IBA
TECHNICAL REVIEW

9

Digital Television Developments

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Contents

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NOTE:

Codes of Practice for Technical Performance.
Under the terms of the Independent Broadcasting
Authority Act 1973 the IBA is required to ensure that high
quality technical standards are provided and maintained.
The Authority's Codes of Practice for Technical
Performance together with other technical data, which are
referred to in the following articles, set out the tolerances
and standards to be aimed for on a day-to-day basis. These
Codes etc. are reproduced in *IBA Technical Review 2:
Technical Reference Book.*

Introduction

by J B Sewter
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It is more than mere coincidence that this is the third volume of *IBA Technical Review* to be devoted to aspects of digital television. It has been pointed out elsewhere that, in the sphere of analogue electronics, television broadcasting remains the biggest bastion.

That this last stronghold must inevitably fall is taken for granted by the majority of forward-looking engineers. The only question is when? Already, the pillars of analogue are beginning to crumble while the early trumpets of digital technology are being sounded—not only in Europe but in North America where, at one time, it seemed that television was permanently entrenched in analogue.

Nowadays, throughout the world, digital technology is increasingly being applied to video processing as in the DICE standards converters, the frame synchronisers and the time-base correctors, and to many aspects of automatic monitoring and control. And, in the important field of teletext, the UK has gained a world lead as it is the first country to establish regular, nationwide, though as yet experimental, data broadcasting.

The present volume contains three articles devoted to aspects of ORACLE teletext and cover the origination of the service which, since 1975, has been a responsibility of members of the Independent Television Companies Association (ITCA). A further article by a member of BREMA on Teletext Receiver Techniques will cover the design of decoders and their implementation by the receiver industry, and will appear in a later issue. This volume also includes articles on more general aspects of digital television i.e. digital transmission via Post Office telecommunication networks; the Digital Automatic Measuring Equipment (DAME) developed in IBA laboratories at Crawley Court, Winchester; a brief review of the questions governing the choice of sampling rate for digital video; and a general purpose 'digital vocabulary' for guiding analogue-orientated engineers through the maze of the new terminology.

Inevitably, digital broadcast television will be delayed by reason of the enormous amount of capital already invested by the public in their analogue receivers. Certainly, few of us will ever reach an era which will be digital all the way. But recent experience suggests that, even where television is broadcast in analogue form, the introduction of digital techniques within studio complexes and intercity distribution networks would afford significant advantages. Compared with analogue techniques digital processing can be controlled more effectively; digital circuitry can be more reliable and signals less prone to noise and distortions; information can be stored and read out at any required rate, the signals being stretched or delayed in time, or compressed within any required time limit; and, with the aid of digital measuring equipment, digital signals can more readily be controlled and monitored.

It might be argued that the additional bandwidth required for accommodating digital signals is a barrier which will not easily be overcome. Yet, while we should not underestimate the problems of digital video, it cannot be too strongly emphasised that telecommunication circuit costs depend, not only on bandwidth, but also on the need for achieving a satisfactory signal-to-noise performance and for minimising those many distortions to which analogue signals are prone. And necessity is a great spur to invention.

It is our hope that this volume of *IBA Technical Review* will contribute to the success of this highly important debate, or at least help other engineers to come to grips with the likely television techniques of tomorrow.

P R HUTT, MA, DIC, joined the IBA in 1970. Since then he has been engaged, almost exclusively, with research and development work in the increasingly important field of digital signal transmission. After completing the early development of a data signalling system for network use, he applied the experience gained to the development of the ORACLE data broadcasting system and has been leader of the project since its inception. He also coined the acronym ORACLE.

Living in the Hampshire Hangars, near Petersfield, which are 800 ft above sea level, he claims that his is one of the 100 highest families in Hampshire. He plays squash, and has a vine and a fig tree.

ORACLE - A Fourth Dimension in Broadcasting

by P R Hutt

Synopsis

ORACLE was the system used for the first ever demonstration of a public information service based on the insertion of data signals in the field blanking of a television waveform. This demonstration, in April 1973, was the spur to a rapid programme of experimentation and development by the IBA and ITCA which together with work done by the BBC and BREMA led to the early publication of the joint Teletext Specification which has since become known as the 'White Book'.

The early publishing of this specification has led to very purposeful activity in the development of transmitting systems and to the design by industry of integrated television/teletext receivers for use by the public.

Intense activity still continues in the fields of research, development and programming, and, with receivers almost ready for the showrooms, ORACLE is now poised, ready to be launched, when required, as a full public service.

The omens for ORACLE are favourable, but only time can tell—or perhaps the original Oracle at Delphi could foretell—the future of the new teletext service.

Introduction

To assess the whole of the ORACLE development at the present time requires the detachment of the historian, the insight of the journalist, and the precognisance of that forerunner of the present service, the Oracle at Delphi. The historical viewpoint is required for picking out the significant events in the rapidly unfolding story, and the insight of the journalist is needed for highlighting the important things that are happening now in what is a very active and widespread field. As for the future, the signs are good, but the final arbiter will be the viewing public.

Whenever any new medium of communication or entertainment is developed there is inevitably a period of uncertainty and scepticism. People question whether it will be successful and then, when it catches on, they begin to show concern for the effect it might have on existing services. More often than not there is room for all; thus, telephones have not ousted the postal services, tape has not replaced disc records, television has not supplanted radio. Similarly, ORACLE is likely to find its slot in the ever expanding and diversifying field of broadcast communications.

At an IEE colloquium, in January 1976, on the subject of teletext over 500 people were gathered, and if success of a project can be gauged by the amount of activity being exerted then ORACLE is already succeeding although, as yet—and most

importantly of all – we are unable to predict the likely degree of public acceptance. However, the omens are good. The market surveys are enthusiastic, and if the past trend continues then only time is required for the story of ORACLE's development to have a happy ending.

Early Events

The seeds of ORACLE were sown at the Authority in 1970. Although there had previously been some research at the Authority and elsewhere to derive some advantage from those empty television lines, it was in 1970 that serious studies were initiated to design a signalling system for the transmission of monitoring data within the television network.

It was soon apparent that a self-synchronising system, incorporating a run-in burst and start code, would be required since the television specification was insufficiently rigid to allow data timing references to be tied directly to it. The work culminated in the system known as Source Label Indication and Control Equipment (SLICE)[1], details of which were published at IBC 72 and in *IBA Technical Review 3*.

The system employed 200 ns pulses as its basic signalling element, and used complementary pairs of these so that the data signal contained no dc component and could be detected without reference to any other television parameter. This system has been further developed by IBA/ITCA for use in the UK national network and by the EBU for transferring data within the Eurovision network.

The concept of a public data service had long been in the minds of IBA engineers whose work included the designing of equipment for Insertion Data Signals (IDS). It required a confluence of circumstances to precipitate the pioneering work which was to result in the world's first demonstration of domestic data broadcasting. First, the IBA was carrying out development work in the field of data broadcasting. Second, the price of integrated circuits was falling. Third, the availability of medium scale integration (MSI) devices such as storage devices, character generators, counters and shift registers enabled the construction, at reasonable cost, of receivers for demonstrating such a service. Fourth, the IBA was ideally placed—with its, now mature, commitment to the application of computers in broadcasting—to apply its programming and design expertise to the development of a data editing, originating, and transmitting system.

Therefore, when in late 1972, the BBC announced plans for an auxilary data service based on a transmission method as yet undetermined, the IBA were, by April 1973, able to give a live demonstration of an edited service. Initially, the system provided 50 pages of text using one line per field and transmitting data from a small general purpose computer employing a video display unit. The biphase SLICE signalling system was employed as data carrier.

Many of the parameters prescribed for the first ORACLE system were to establish the character of the eventual UK TELETEXT standard. Looking back, it is somewhat surprising how so little psychophysical investigation of the necessary display and transmission parameters was undertaken. The parameters used in those first transmissions were set by a combination of engineers' good sense and what the technology then allowed. Such features as forty characters per line, page-sequential and adaptive transmission, and computer controlled origination were all included. Others, such as 6-dot display graphics, lower-case characters, colours and space displayed control characters came later.

One important task, which was far from easy, was that of finding a suitable name for the project, and the team spent many a lunch hour sifting through endless possibilities. Finally, the author hit on the idea of the name 'ORACLE' one Sunday while lunching with friends. Being a classical source of advice and information the name seemed to be very apposite, and it was not long before it was made into an acronym for 'Optional Reception of Announcements by Coded Line Electronics'.

The Development

1973 and 1974 proved to be the most important years in the development of ORACLE. After the first ORACLE experiments, the BBC demonstrated that their CEEFAX system was, after all, also going to employ an IDS as data carrier. The basic pulse rate selected was 4.5 Mbits/s without the complementary coding of the SLICE signalling system. This was a sensible decision in the light of the large quantity of information a domestic information system would be required to transmit. However, the CEEFAX signal otherwise was virtually very similar to the first ORACLE signal. It likewise possessed a non-return to zero (NRZ), self-synchronising start-code initiated, format. The difference lay in the secondary coding which, in

CEEFAX, consisted primarily of 8-bit odd-parity character coding as opposed to the complemented bit coding of ORACLE.

It was obviously desirable that there should be only one technical standard in the United Kingdom, and so an executive committee under the chairmanship of K S Spencer (the Spencer Committee) was set up at the instigation of the IBA, the BBC and BREMA (the British Radio Equipment Manufacturers' Association) to recommend a common standard.

Much hard work, discussion and experiment took place during the following 18 months under the auspices of the tripartite Spencer Committee and its working group. An early fundamental decision was made, that the data service should have as fast a response time as possible. This meant that once an acceptable response time could be agreed, the number of pages available could be maximised. That decision led to the requirement that one blank television line should carry one row of text. And that in turn led to the requirement of 360 bits per line and a data rate around 7.0 Mbits/s.

In the event these objectives proved less difficult to realise than had been expected. Early field work showed that such a data rate was quite feasible, as had indeed been first demonstrated in theory by Nyquist[2]. The feasibility of this meant that a final standard could be proposed allowing transmission of a full page of almost 1,000 characters in just 0.25 s. This was a considerable advance on the 0.5 s per page for CEEFAX and the average of around 0.8 s of the original ORACLE system.

Data transmission rate, character codes, control codes, control bits, display modes, boxing, graphics facilities, Hamming address protection for row and page addressing, – these were just some of the matters that had to be thrashed out by the working group. Finally, a TELETEXT specification[3] was agreed. This was published in time to be available at the important forum of IBC 1974 where it was presented to the world's leading broadcasting organisations as a unified UK standard. It was this achievement that gained the IBA/BBC/BREMA teams the 1976 Royal Television Society award for technical innovation in television. Simultaneously, there were several receiver manufacturers ready to demonstrate their prototype receivers.

Field Trials

In the development of broadcasting it is most important to try to avoid a profusion of standards such as, lamentably, was the case with colour television. In fact, bearing in mind that at the time of its printing few tests had been performed and no results of any field tests had been published, the first teletext specification has stood the test of time remarkably well.

After the International Broadcasting Convention held in London in 1974 (IBC 74) the broadcasting organisations together with BREMA ventured with renewed vigour into the tasks of designing receivers, testing the transmissions, examining the behaviour of teletext signals on the network, through main transmitters, through rebroadcast and relay transmitters, in multipath receiving situations and in the intermediate frequency stages of television receivers. In fact, the whole of the television system from studio to living room had to be re-examined with ORACLE in mind.

With the publication of the specification, which came to be known as the 'White Book', the integrated circuit manufacturers could consider design projects that would reduce the number of integrated circuits used in receiver decoders from the 100 or more necessary when medium scale integration (MSI) is used to 10 or so as required in the case of large scale integration (LSI). Companies could design and market development models of teletext decoders for video signals in studios, integrated uhf teletext receivers for domestic use, and adapters for fittings in the aerial leads of unmodified conventional television receivers. Activity in the teletext field went ahead at great pace chiefly by reason of the existence of a published standard.

In the spring of 1975 a particularly important series of tests was conducted by the IBA in conjunction with the BBC and with the co-operation of the Institut für Rundfunktechnik GmbH (IRT) in Bavaria. It was there that the new teletext standard was to undergo its first continental trials. These were very significant, and for two reasons. First, it was important to verify that the 144 ns pulses would, as theory had predicted, be able to cope with the narrower 5.0 MHz channels of the European Systems B (vhf) and G (uhf). And second, if that were so, the attractive prospect of a single

teletext standard being possible for the whole of PAL-Europe would then present itself.

Fortune indeed smiled on teletext. The Bavarian tests were very positive; only a small number of served television viewers would be unable to receive a teletext service. These tests spurred a radical improvement in our understanding of data transmission on television networks.

It was following these tests that the concepts of teletext pulse response, pulse height, intersymbol interference, eye-height function, eye width and eye diagrams began to find concurrency in the language used by television engineers. Following the test in the Federal German Republic[4] a series of tests in the South of England[5, 8] confirmed the viability of the specification, and the outcome of these trials has produced an effect on the public not greatly different from that which was anticipated just prior to the introduction of colour television.

By now the teletext signal has been tried and tested using 5 MHz television systems in Bands I, III, IV and V, and 5.5 MHz systems in Bands IV and V. All these trials have tended to confirm that the vast majority of people already served with colour television will also be able to receive teletext. In some cases, viewers will need to give just a little more attention to their aerial systems to ensure they receive an error-free ORACLE service. The following Table indicates the extent of good reception of television/teletext signals under different conditions, but within the recognised service area of a transmitter.

It can be seen that the teletext signal is just a little more dependent on aerial efficiency than the colour

Table 1

INCIDENCE OF GOOD ALL-CHANNEL RECEPTION

TYPE OF AERIAL	SOUND	SOUND LUMIN-ANCE	SOUND LUMIN-ANCE AND CHROMIN-ANCE	SOUND LUMIN-ANCE AND CHROMIN-ANCE AND ORACLE
Piece of wire	Always	Usual	Occasional	Spasmodic
Set-top aerial	Always	Always	Usual	Occasional
Roof mounted aerial	Always	Always	Always	Nearly Always

signal; even so, in cases of reception limited by field strength only, a teletext service can be perfect when the colour picture has become very poor. With a signal/noise ratio of, say, 23 dB a very poor colour picture results, but at a site with an efficient and unobstructed aerial, almost perfect teletext reception is possible.

Signal Measurement

The period following IBC 74 and the publishing of the 'White Book' was one of intense testing as has been described above. The techniques of measurement were developed as the testing proceeded.

A companion paper in this edition, entitled 'The Numerical Basis for ORACLE Transmission', by K Lucas, discusses in more technical detail the degradation that can occur in the teletext signal as it travels from studio to receiver. In particular, the concept of eye-height is explained as the critical parameter which defines the quality of the teletext signal at any point. Work is in hand to correlate the traditional parameters used for measuring television performance with the measurement of the teletext eye-height. The eye-height is, however, a complicated function of the teletext pulse and involves an infinite summation of magnitudes.

Some surprises have occurred in the course of measuring and testing teletext. One particular surprise was that break-through from the data transmit clock was apparent when the received transmissions were viewed on a spectrum analyser tuned to 7.0 MHz. Although it appears above the sound notch at 6 MHz, it is still within the pass-band of some PTT links and consequently can be transmitted over air at a level high enough to be discernible with a spectrum analyser on the output of a receiver.

Another surprise has been the accuracy of the most obvious means of measuring eye-height, i.e. by merely gauging the separation between top and bottom cusps in a displayed data waveform. In the majority of circumstances the 'tram-line' eye method, as it is called, can be expected to yield a result well within 5% of the correct value[6].

Yet another unforeseen effect was 'buzz-on-sound' which, at one time, was a matter of great concern. However, it transpires that it is due to non-linearities, of third order and above, in the RF-to-baseband detection process. Energy containing sum and difference components of the

harmonics of data and character rate can appear in the 6.00 MHz sound region and can cause a buzzing sound in certain receivers. This buzz is usually of a fairly low level, but it has been found to be far worse when the receiver is displaying certain television captions. In nearly all cases, adjustment of the sound circuits in the receiver has reduced it to small proportions. So the buzz-on-sound problem, although more than trivial, can now be regarded as not being serious. Even so, in conjunction with the other small problem of data display on frame flyback, it has contributed to the need for keeping the nominal data level at 0.5 v or just below, rather than at the 0.7 v peak-white level theoretically available.

System of Editing
At IBC 74, HRH the Duke of Kent announced the start of a two year period of experimental ORACLE transmissions. In mid-1975 the IBA largely delegated the responsibility for originating this experimental service to a team newly formed by the Independent Television Companies' Association (ITCA), who by then had developed a new and powerful computer-based editorial and transmission system with which to provide an experimental service retaining the name ORACLE. The problems and achievements of the system are fully described elsewhere in this edition.

The system will not be further described in this article, but it is pointed out that this system has allowed ITCA to make a very positive contribution to the finalisation of the teletext specification, particularly in the portions concerned with editorial matters. Such details as the boxing of displays, graphic display, background colours, and double-height characters are now receiving attention by ITCA, so that one or two additional parameters can be included in the final issue of the specification.

Teletext Receivers
An essential and concomitant part of the development of ORACLE which accompanied the programme of field testing and research was, of course, the development of ORACLE receivers, and associated circuits and devices, which is still progressing.

A matter which greatly affects the design of receivers is the finalisation of those last minor points of the specification. The first 'White Book' was re-issued as a simplified document for an IEE

Colloquium in January 1976. At present, the receiver manufacturers and the broadcasters are jointly on the last lap of finalising a revised specification which shows little major change since the first issue.

However, from the points of view of the designers of receivers and integrated circuits, even minor amendments can be important. In the early days of teletext the view was prevalent that receiver manufacturers should have great latitude in exercising certain options in the displaying of received text; but, at that period, only upper and lower case alpha-numerics were envisaged. However, as the number of display facilities in the specification has grown, it has become increasingly necessary for the editors of the system to know precisely how a message appears on a viewer's receiver, and to ensure its meaning does not become lost or distorted. Hence, the present trend is increasingly towards a 'fixed' receiver strictly in accordance with a specification which leaves little scope for options.

One very important parameter is the eye-height figure which could be taken as being acceptable for commercial receivers. Receivers developed by the IBA and operating from a video signal have given error-free performance with eye-heights below 10%. For the integrated television/teletext receiver, fed from a conventional UHF aerial, the problems are somewhat larger. This is because they involve intermediate frequency characteristics together with other problems arising from any locally generated noise or crosstalk. An eye-height of 25% has been accepted as a reasonable figure on which to base teletext service area coverage, and this same figure has also been agreed by BREMA as a design figure for receivers.

Receiver timing circuits, likewise, need to be borne in mind when specifying the transmitted data signal. Receivers may contain one of three possible types, namely, fixed-frequency circuits, line sync 'phase-locked loop' circuits and high-Q tank circuits. As a result, a tolerance of around 1 part in 10^4 for the data transmit frequency, together with a rather tight jitter restriction is necessary if neither type of receiver is to be placed at a disadvantage.

Uses and Opportunities
Teletext can be used in several different ways which may be categorised into three main groups according to whether or how the information is related to the current television programme.

The simple case is that in which the information is entirely divorced from the television programme. In this, only the line and field syncs of the video signal (or possibly less) are needed to allow the signal to be decoded. Such information provides the conventional type of information service dealing with matters like weather, sports results, 'Top Twenty', gardening advice as used when the service was first demonstrated in those original ORACLE broadcasts in 1973. Also in this category is information which may be of an advertising nature, and, for example, it could include commercial information from wholesalers to retailers, head office to branch offices, etc. The use of teletext as a communication channel of this type has been studied in great depth by T Johnson[7] who predicts that it has a definite commercial future. It will, of course, depend on the availability of sufficient transmission time or capacity, and on governmental sanction. It could eventually extend into the full-field data broadcasts outside normal programme hours.

The second category is that in which the teletext information is associated with the context of the television programme, but without the need for very precise synchronisation. One example of this type is teachers' notes accompanying schools programmes. This application has been the subject of recent experiments by IBA/ITCA. Other examples are test match score cards, election results, ingredients for cookery programmes, and serial story presentations.

In the third category the teletext information is associated with the television programme both in context and in time. The most obvious examples are sub-titles for minority language audiences or, more significantly, for the deaf. Here again experiments have been conducted by the IBA/ITCA. Deaf viewer captions have also been seriously studied by the Public Broadcasting Service of the United States (though using a different data system) and results so far have been encouraging.

The programming use of ORACLE can be considered only briefly in an article of this nature. However, it will be understood even from this short account that ORACLE is beginning to change the very concept of television broadcasting. The scope of television will be much broadened by the realisation of this

extra dimension, and with no extra call on the precious frequency allocations it is truly something for nothing.

The Future
As stated, the final version of the UK's teletext specification will be published this autumn. This will differ from the earlier version only in the significance of some of the bits contained in the signal; the signal shape itself will be exactly similar to that first described in the 'White Book' of October 1974. Receiver integrated circuit manufacturers will then have no barrier against finalisation of their designs for the eventual production line. Indeed, BREMA have their own privately sponsored market survey to speed them in their race to the market place.

Meanwhile, ORACLE editorial staff have the problem and the challenge of structuring their information service such as to provide a useful, profitable and regional service to the viewers at large. Experiments in the use of ORACLE will continue to reveal new ideas and new applications.

The IBA is developing the means of measurement and performance assessment of ORACLE signals. Quality control of the ORACLE signal must be specified and measurement defined. Equipment now in course of design will ensure that the right parameters will be measured in the best possible way to provide maximum service area for the ORACLE signal.

Finally, it will be the viewers who purchase teletext receivers and make use of the service who will reward the design engineers and programmers by their continuing demand for information in the form of ORACLE. The experimental ORACLE service is using only two lines of blanking per field. The specification allows use of other unallocated lines. One is tempted to wonder how long it will be before most of those lines are taken up in meeting the demands of the service.

Conclusions
It has been seen how ORACLE has progressed from those first pioneering experiments to take advantage of the unused part of the television waveform, and is now developing to give broadcasting a new dimension. Activity has been steadily on the increase since the early days of 1972. The exponential curve crossed that zero-time axis

at the Colloquium on Teletext in January 1976 when all previous IEE attendance records were broken. And shortly we hope the experimental service will move from its pilot stage and become a fully-fledged public service.

Could it be that when Tennyson wrote
For I dipt into the future, far as human eye could see,
Saw the Vision of the world, and all the wonder that could be.
he had consulted the Oracle concerning ORACLE?

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KEITH LUCAS, MSc, PhD, graduated in 1967, and afterwards spent four years at Southampton University on research in the field of Artificial Intelligence and Adaptive Control Systems. He was then employed by the Plessey Company and was engaged in defence projects. Since joining the Authority in 1974 he has been working on the ORACLE project in the Automation and Control Section of the Experimental and Development Department.
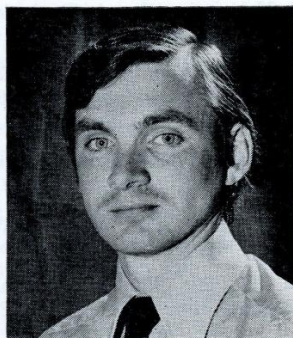
The Numerical Basis for ORACLE Transmission

by K Lucas

Synopsis

During the past few years the ORACLE system has progressed from a laboratory demonstration to an experimental public service which is already available to a significant proportion of the population. In the near future, television manufacturers will begin to offer integrated teletext decoders to the public at large. The intervening period of perhaps a year will be used by broadcast engineers to establish any new measurements and procedures which might be required to accommodate the new service.

This article reviews some of the work which has been carried out to establish the basic requirements of data signals in the television system. It defines the susceptibility of data signals to distortion and noise from various sources, and leads to a consideration of the levels of distortion and noise which occur in the television network, and the implied service coverage which will result.
Current development work is also discussed, including the optimisation of teletext pulse shape, and the measurement of signal quality.

The Teletext Waveform

The data signals are inserted during the field blanking interval, as shown in Fig. 1, on lines 17, 18, 330 and 331. Figure 2(a) illustrates an ideal data waveform in which a logic [1] is signalled by the presence of a raised cosine pulse of amplitude 0.5 v and width 144 ns. A logic [0] is signalled by the absence of a pulse (black level).

For the purpose of analysis, it is more convenient to regard the data as a sequence in which a [1] is signalled by a half-amplitude positive pulse, and [0] by a half-amplitude negative pulse, see Fig. 2(b). This formulation underlines the equivalence of [0] and [1] signalling, and thereby avoids confusion which occasionally arises when the more obvious approach is used. The precise conditions under which the transformation can be made are established in Ref. 1. The transformation is always possible with pulses which occur in the teletext waveform provided that linearity is maintained.
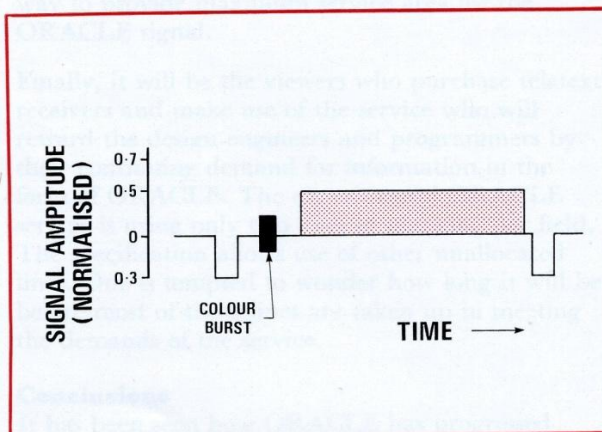

Fig. 1. According to the present waveform specification, data signals occupy the active line period of two lines of blanking per television field. The actual lines used are those numbered 17, 18, 330, 331.
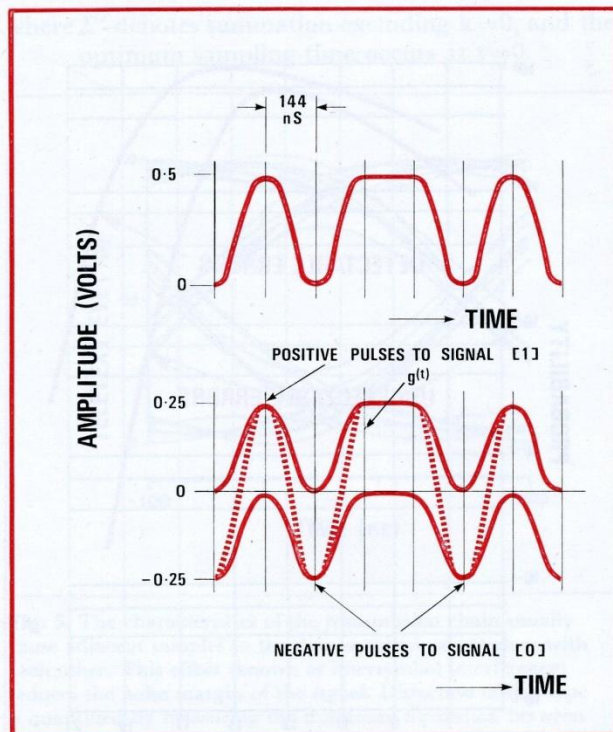
Fig. 2. Raised cosine data may be constructed (excluding a 0.25 v offset) by summing a series of positive and negative half-amplitude pulses. The diagram shows a typical data signal with its positive and negative components. This formulation preserves the equivalence of [0] and [1] signalling.

A sequence of eight bits forms one data word, and there are 45 data words to each row of text. A typical row of text is initiated by five control words which assist the decoding and provide information about the text to be transmitted. The remaining 40 words each represent one display character. The structure of the coding is fully described in Ref. 2.

Susceptibility to Noise

A data receiver makes a binary decision based on the value of the signal at the instant of sampling. Referring to Fig. 2(b), if the value of the signal is greater than zero the binary digit is assumed to be [1]; otherwise a logic [0] is assumed. This type of data receiver is said to be a 'fixed slice, zero threshold receiver'. In general the decision reached is given by:

$$D = [1] \text{ if } g(t_0) > \alpha \left.\right\} \qquad (1)$$
$$ = [0] \text{ otherwise}$$

where, t_0 = the sampling instant
α = the decision threshold or 'slice level'.

'Fixed slice' receivers are so described because the decision threshold, α, is independent of the received signal. In linear systems the optimum decision threshold (i.e. that which maximises the noise margin) is always at zero, i.e. $\alpha = 0$.

When Gaussian noise is added to the data signal, an error will occur only if the noise voltage at the sampling instant exceeds 0.25 v, and is of the required polarity. The probability of a single error is therefore given by integration of the normal probability density function:

$$P(\sigma) = \int_{0.25}^{\infty} \frac{1}{\sigma\sqrt{2\pi}} e^{-y^2/2\sigma^2} \, dy \qquad (2)$$

where σ is the rms noise voltage.

This equation leads to the graph shown in Fig. 3 which relates the error probability to the video signal/noise ratio for data signals.

Figure 3 alone does not define the susceptibility of the system to noise. Due to the structured coding of the signal, the effect of a single bit error depends upon where it occurs. For example, control information is protected by a Hamming code which is capable of correcting isolated errors. The security against errors afforded by the teletext coding has been fully investigated[3]. One conclusion derived from this work is that the performance of teletext in the presence of noise is limited by the vulnerability of text information, rather than control information. With video signal/noise ratios of less than 19 dB, the number of errors and omissions in the text that are displayed on the screen becomes unacceptable to the viewer. This result is illustrated by the graph of Fig. 4 which shows the probability of visible text errors and omissions plotted against signal/noise ratio.

A signal/noise ratio of 19 dB corresponds to a bit error probability in the region of 10^{-3}. This figure will be used in defining the acceptable limits of the ORACLE service.

Eye-height

The parameter which is usually used as a measure of the quality in data waveforms is known, for reasons which will become apparent, as eye-height. Referring to equation (1) the eye-height of the data is defined as the maximum variation in the decision threshold, α, which can occur before the onset of
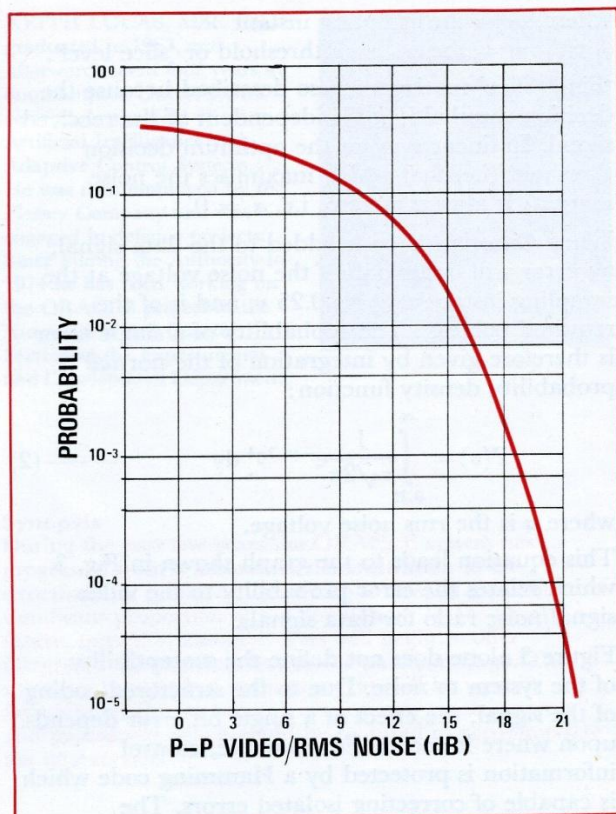
Fig. 3. The probability of isolated bit errors. In the absence of distortion (both linear and non-linear) there is a simple relationship between teletext error-rate and signal/noise ratio. The effect of isolated errors on the quality of service is determined by the protective coding in the ORACLE system. It is found that an adequate service results when the error rate is less than 10^{-3}.

Fig. 4. The probability that any text row will be acceptable and contain at least one error. The performance of ORACLE in the presence of noise is limited by the vulnerability of text information. At a signal/noise ratio of 19 dB, each newly acquired page will possess several errors (displayed as blanks). In general these errors will be corrected on the second acquisition.

errors (the optimum choice of sampling instant being assumed). For the ideal data of Fig. 2(b), the slice level can vary from -0.25 v to $+0.25$ v without causing decision errors; in this case the eye-height is 0.5 v. It is conventional to normalise this value by expressing it as a fraction of the data amplitude, i.e. the voltage difference between the steady states for [0] and [1]. Ideal data therefore has an eye-height of unity or 100%.

An important property of ideal data is that the value of the signal at any sampling instant is independent of the surrounding sample values. When data is passed through a linear network with arbitrary characteristics, the independence is lost, and the signal is said to suffer from intersymbol interference (ISI). In data having ISI, there will
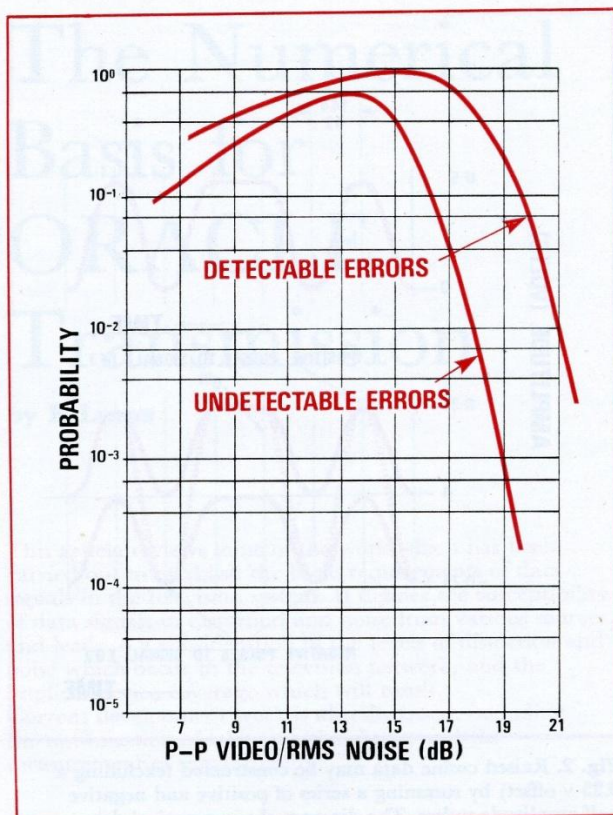
always be some combination of surrounding sample values which maximally reduces the value of a logic [1] sample. In consequence, ISI always reduces the eye-height (and the noise margin) of the data.

If it is imagined that the voltage waveforms for successive sample periods be superimposed, the result is a diagram similar to Fig. 5. The minimum separation between [0] and [1] assumes the characteristic eye shape which is the source of the term eye-height.

Figure 6 shows the response of a network to a single teletext pulse. It may be shown[4] that the eye-height, h, of this system is given by:

$$h = f(0) - \sum_{k=-\infty}^{\infty}{}' \, | \, f(-kT) \, | \qquad \text{———(3)}$$

where Σ' denotes summation excluding $k=0$, and the optimum sampling time occurs at $t=0$.
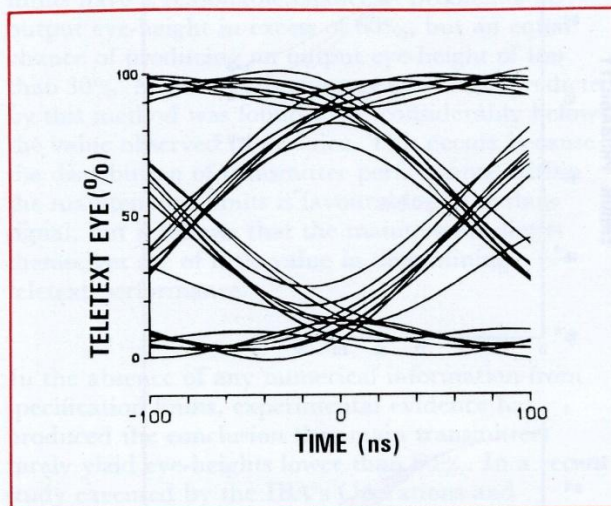

Fig. 5. The characteristics of the transmission chain usually cause adjacent samples in the data sequence to interfere with each other. This effect (known as intersymbol interference) reduces the noise margin of the signal. Distortion of this type is quantified by measuring the minimum separation between logic [0] and logic [1] signals using an 'eye-diagram'. The eye-diagram shown above is formed by the superposition of the data waveforms from successive bit periods, and represents an eye-height of 47.9%.
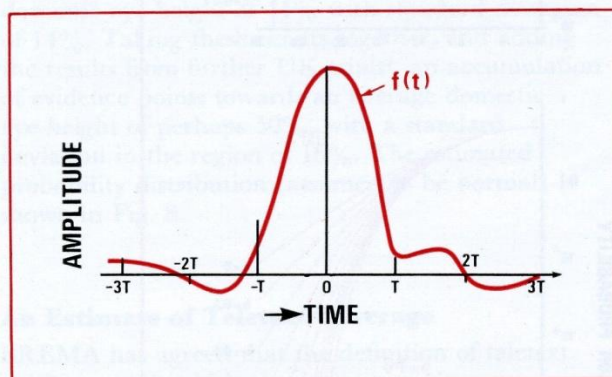

Fig. 6. The diagram shows the 1.44 T pulse response of a transmission channel which introduces intersymbol interference. The reduction of eye-height caused by the interference contributions $f(kT)$ is equal to the sum of their moduli $\Sigma' \mid f(kT) \mid$

Susceptibility to Linear Distortion

Intersymbol interference caused by components in the television network always results in reducing the eye-height of the signal, and thereby increases the problems associated with reception. In principle, the distortion can become so severe that the eye-height is reduced to zero, and error-free reception becomes impossible with a fixed-slice unit. It is usually possible to recover the loss in eye-height by appropriate equalisation[5] but this technique is thought to be somewhat impracticable for domestic reception.

Only in exceptional circumstances will the eye-height be reduced to zero: normally the loss of eye-height shows up as a reduction in the noise immunity of the data signal. It therefore becomes necessary to examine the effect of linear distortion in conjunction with additive noise. An analysis[4] of this problem has been carried out, and the major conclusions are expressed in Fig. 7 in which the curves show the relationship between the probability of bit errors and the video signal/noise ratio for a wide range of linear-distortion conditions. These theoretical results have been confirmed by experimental measurements both in this country (uhf System I) and in the Federal German Republic (vhf System B).

The Transmission of Teletext Signals

The graphs of Fig. 7 summarise the susceptibility of a teletext signal to distortion and noise. Turning to the television transmission network, an attempt is now made to assess the levels of distortion and noise which are likely to occur in practice.

IBA transmitters are designed and maintained to specified limits which ensure adequate performance with video signals. These System Maintenance Limits are given in Table 2 on page 6 of *IBA Technical Review 6*. This table comprises a list of parameters which together determine the transmitter performance limits in time and frequency domains. The relationship expressed in equation (3) shows that the eye-height of the data signals depends entirely on the shape of the pulse response. Only in so far as the transmitter maintenance limits restrict the 144 ns pulse response will they also limit the degradation of the data signal as a whole.

The transmitter video specifications have been studied in some detail to determine the way in which they control the quality of data signals. The outcome of this study[6] was an analysis which suggested that a poor ORACLE performance could occur with transmitters which conform to the existing
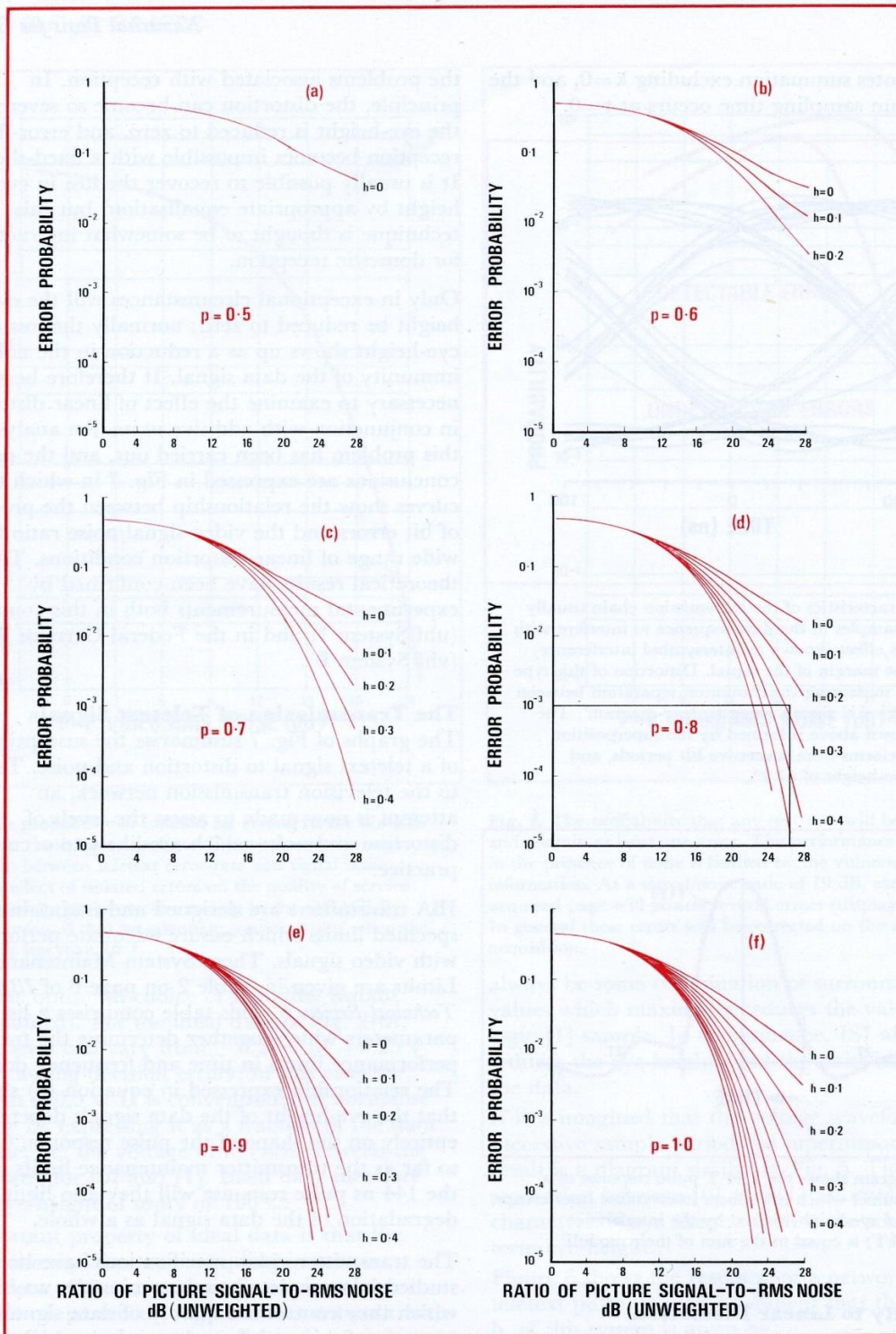
Fig. 7. These curves show the theoretical relationship between error-rate and signal noise ratio for varying degrees of intersymbol interference. In particular (d) shows that a satisfactory service (with error-rate below 10^{-3}) will result when the signal noise ratio exceeds 26.5 dB. In consequence, the transmitter service area for ORACLE should be at least as large as for video signals (p=teletext pulse/bar ratio, h=eye-height).

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video requirements. The results predicted that transmitters performing within the maintenance limits have a reasonable chance of producing an output eye-height in excess of 60%, but an equal chance of producing an output eye-height of less than 30%. Moreover, the average eye-height predicted by this method was found to be considerably below the value observed in practice. This occurs because the distribution of transmitter performance within the maintenance limits is favourable to the data signal, but it follows that the maintenance limits themselves are of little value in determining teletext performance.

In the absence of any numerical information from specification limits, experimental evidence has produced the conclusion that main transmitters rarely yield eye-heights lower than 60%. In a recent study executed by the IBA's Operations and Maintenance Department[7], the average recorded eye-height from main transmitters was found to be 72% with a standard deviation of 8.2%. By the time the signal had reached the domestic television receiver, the linear distortion, mainly due to multipath propagation and aerial mismatch, had reduced the eye-height to a mean level of 56% with a standard deviation of 17%. Similar tests carried out in Germany[8] suggest an average domestic eye-height of 44% with standard deviation of 14%. Taking these results together, and adding the results from further UK trials[9], an accumulation of evidence points towards an average domestic eye-height of perhaps 50%, with a standard deviation in the region of 16%. The estimated probability distribution (assumed to be normal) is shown in Fig. 8.

An Estimate of Teletext Coverage

BREMA has agreed that the definition of teletext service area should be based on a minimum domestic eye-height of 25% available at the receiver aerial socket. However, the areas in which the signal fails to meet this requirement will not always be those which are most distant from the transmitter as isolated pockets of ISI are likely to be caused by local reflecting objects. *The distribution shown in Fig. 8 indicates that, in areas of high signal strength, the teletext coverage (with eye-height above 25%) is likely to exceed 94% of the population.*
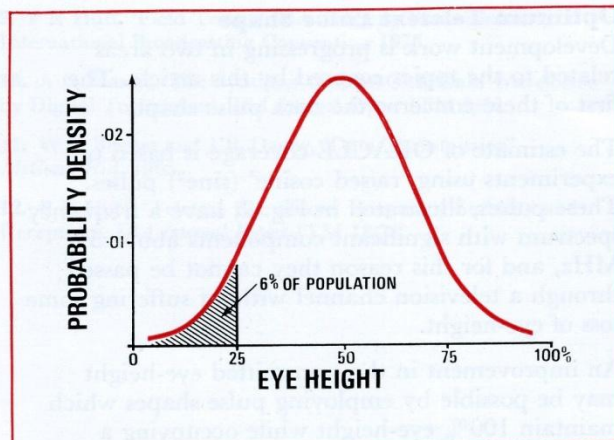

Fig. 8. Field trial results suggest that the average domestic eye-height is likely to be approximately 50% with a deviation of 16%. If the distribution is normal, these estimates suggest that 94% of the population will receive an eye-height in excess of 25%.

Founded, as it is, on a diversity of measurement sources, this estimate is a hybrid based on vhf/uhf tests in the UK and the Federal German Republic. However, it serves the main purpose, which is to demonstrate that the great majority of viewers should be able to receive the new service.

An Estimate of Teletext Service Area

In estimating service area, the effect of additive noise must be taken into account. The theoretical curves of Fig. 7 may be used for this purpose, Fig. 7(d) being appropriate for a typical transmitter. It has been shown that a satisfactory teletext service will be achieved when the bit error-probability is less than 10^{-3}. Fig. 7(d) indicates that an ideal receiver will, when presented with 25% eye height, function with an error rate below 10^{-3} for signal/noise ratios in excess of 26.5 dB. Since the video signal/noise ratio in the service area is always greater than 29 dB, there is a small margin in hand. *It follows that the estimated 94% coverage is likely to extend to the limits of the service area of a typical transmitter.*

The numerical results which have been obtained from theory and experiment during the last two years fully justify the design decisions embodied in the original teletext specification[2]. It seems that the final teletext specification shortly to be published will differ from the original only in detail.

Optimum Teletext Pulse Shape

Development work is progressing in two areas related to the topics covered by this article. The first of these concerns the data pulse shape.

The estimate of ORACLE coverage is based on experiments using 'raised cosine' (sine^2) pulses. These pulses, illustrated in Fig. 2, have a frequency spectrum with significant components above 5.5 MHz, and for this reason they cannot be passed through a television channel without suffering some loss of eye-height.

An improvement in the transmitted eye-height may be possible by employing pulse shapes which maintain 100% eye-height while occupying a minimum of bandwidth. These pulses should be immune from the allowable variations in transmitter characteristics at high video frequencies.[10,11] Initial results suggest that an eye-height improvement of 10% can be achieved in some cases by using minimum bandwidth data. It remains to be seen whether more extensive trials will confirm these measurements.

Measurement of Data Quality

The second area of development concerns the monitoring of data waveforms. The eye-height of the data is obviously a very basic criterion of signal quality, and adequate measurement techniques must be available to maintenance teams. It has been shown[7,12] that a good estimate of eye-height can be achieved merely by close examination of the data waveform, but it is considered that an instrument for displaying the eye-pattern explicitly should be available. Such instruments might be used for purposes of reference, and be retained on a regional basis.

Experimental eye-height displays have been produced in prototype form, and Fig. 9 shows examples of one in use. An eye-height display is produced by feeding a sub-multiple of the data clock-frequency to the horizontal deflection of an oscilloscope while the signal itself is fed to the vertical deflection. This results in a Lissajous figure which superimposes successive sample periods to produce the eye pattern. Several methods are available for obtaining the data clock signal, and an instrument now being developed offers the user a choice of these.
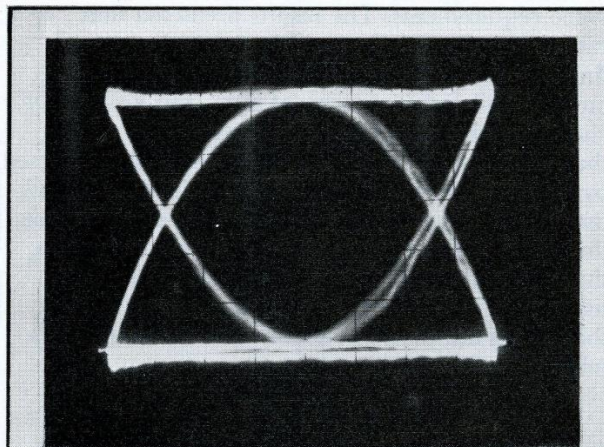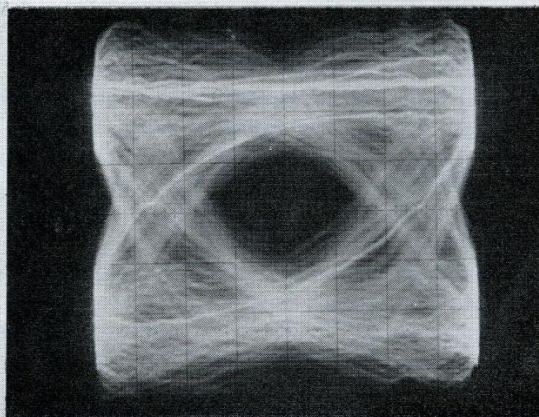

FIG 9a

FIG 9b

Fig. 9. These photographs were recorded using an experimental eye-height display. Fig. 9(a) shows the eye-pattern for raised cosine data before transmission. The eye-pattern of Fig. 9(b) shows the effect of intersymbol interference, which in this case reduces the eye-height to 40%.

2. 'Specification of Standards for Information Transmission by Digitally Coded Signals in the Field-Blanking Interval of 625-Line Television Systems', Joint Report BBC/IBA/BREMA, October 1974.

3. K Lucas, 'Security of Coding in the ORACLE System', *IBA, E&D Report* 108/74, UDC 621.397.5.655.

4. K Lucas, 'The Effect of Intersymbol Interference and Gaussian Noise on the Reception of Teletext Signals', *IBA Internal Report* ITM 11/76.

5. K Lucas, 'A Transversal Equaliser for the Removal of Linear Intersymbol Interference', *IBA Internal Report* ITM 2/75.

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8. 'Teletext Field Tests in Bavaria', April 16th–24th 1975, Joint Teletext Working Party Report, August 1976.

9. P R Hutt, 'Field Tests of IBA Teletext Transmissions', International Broadcasting Convention 1976.

10. A G Mason, 'The Synthesis of ORACLE Data Waveforms by Digital Techniques', *IBA Internal Report* ITM 9/76.

11. W R Bennet and J R Davey, 'Data Transmission', *McGraw Hill*, 1965.

12. P R Hutt, 'Teletext Eye Shape, Frequency Stability and Reception', *IBA Internal Report* ITM 13/76.

NORMAN GREEN was born and educated in London and started his career as a student apprentice with EMI. He later joined The Rank Organisation and worked on the development of logic circuits for use in computers, and also on the use of lasers for communication purposes. Since working in television, first with ABC Television Limited and subsequently with Thames Television Limited, he has been involved with the problems of viewing conditions for television and film, and with the application of digital techniques to television studio operations. He subsequently joined the Quality Control Section of the IBA and is now Co-ordinating Engineer with the Independent Television Companies Association. It is from this position that he has been responsible for engineering the experimental ORACLE origination service for ITV.

JOHN HEDGER was born in 1957 and educated in London. He joined London Weekend Television Limited in an administrative capacity, but soon moved to programme production where he spent some time working on children's programmes. He joined the LWT ORACLE editorial team at the commencement of the project since when he has been closely involved with the technical and editorial development of the system.

ORACLE on Independent Television

by N Green and J Hedger

Synopsis

In October 1974 the Independent Television Companies Association, decided to conduct an investigation into the engineering of a teletext service from both editorial and engineering viewpoints. On 30th June 1975 a fully engineered service based on three computers commenced operation employing two editorial units, one for general information, the other for news. Since that time many editorial and engineering experiments have taken place and several improvements to the published teletext signal specification have been made.

The first part of this article explains the *modus operandi* of the experimental system, and the second describes the history of the project and examines the editorial aspects in detail.

INTRODUCTION AND GENERAL DESCRIPTION

Independent Television consists of a federated group of 15 programme companies under contract to the IBA and operating in 14 regions of the United Kingdom, and it was decided in late 1974 to operate an experimental teletext service in the London area to investigate editorial and engineering problems.

Because of this regional structure it was necessary to design a system which would be capable of being expanded to allow all 15 programme contractors to operate a regional teletext service, but this in turn has meant that, as the ITV regions are interconnected as a national network at certain times of the day only, it was initially not possible to provide a 100% ORACLE service outside London, see Fig. 1.
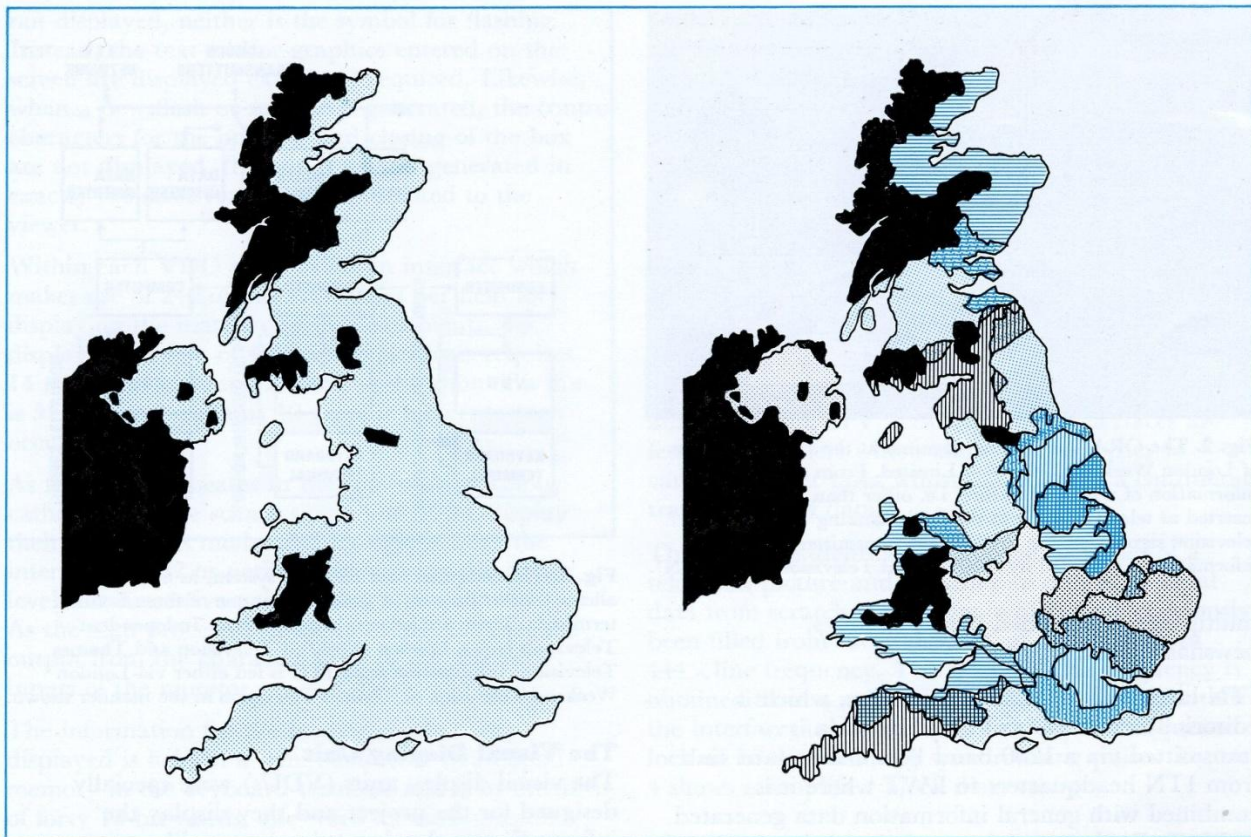
Fig. 1. The map on the left indicates the coverage provided by ITV as a corporate body. In fact, for the purposes of ITV the United Kingdom is divided into 14 regions, as shown by the map on the right, which are served by 15 separate programme companies. (The franchise for the London region is shared by Thames Television Limited and London Weekend Television Limited.) Thus, the ITV regional companies normally operate independently, and the regions are interconnected to form a national network only at certain times and for specific purposes.

The ITV national news service is provided by Independent Television News Limited (ITN), which is jointly owned by the 15 regional programme companies, and it was therefore logical that the news contribution to the ORACLE programme should be originated at ITN headquarters. On the other hand, for the general information service it was decided to base the editorial unit at the studios of London Weekend Television (LWT) which, with the other London programme contractor Thames Television, shares the programme franchise on the basis of 2½ and 4½ days respectively. The computer systems had to be designed for inserting teletext data into the output signals from Thames and LWT prior to their being fed to the London transmitters, and into the

network feed to the other thirteen programme regions. This arrangement allows ITV companies outside London to transmit ORACLE data when receiving programmes from London.

The ORACLE installation at London Weekend Television is shown in Fig. 2.

The Overall System

The system that commenced operation in June 1975 is shown in Fig. 3. The computer and editorial system were designed to allow all the features specified in the joint IBA/BBC/BREMA teletext specification published in October 1974 to be used and tested. This specification provides for eight magazines each of up to 100 pages, and includes

Fig. 2. The ORACLE editing terminal at the London studios of London Weekend Television Limited. From this terminal, information of a general nature, i.e. other than news, is inserted as teletext data into the field blanking of the normal television signals feeding the London transmitters. News information is provided by Independent Television News (ITN).

Fig. 3. The computer and editorial system, as at present, allows teletext data to be generated at one of three London terminals. These are located respectively at Independent Television News, London Weekend Television and Thames Television. Information from ITN is fed either via London Weekend Television or Thames Television in the manner shown.

multipages, time coded pages, subtitles, newsflashes, etc.

ITN have their own news magazine, which is editorially exclusive to ITN. This data is transmitted via a 1200 baud Post Office datel link from ITN headquarters to LWT where it is combined with general information data generated at LWT. During weekday periods this is transferred to the Thames computer installation by another datel link. When a national system becomes available all regional computers will be linked to ITN for the national news contribution, but regional information will be generated by local editorial teams.

Hardware

The computers used in the project are of type PDP 11/10 which use a 16-bit word length and contain 28 K words of core storage. This storage is backed up by a 1.2 million word disc on which is stored the system software, plus all the data for transmission. Additional storage on the system is provided by magnetic tape cassette and paper tape facilities. The magnetic tape cassettes are used for long-term storage of such magazine data as is required only at infrequent intervals, e.g. at Christmas.

The data is entered into the system either by means of keyboards connected to full colour visual display units, or by using paper tape or magnetic tape cassettes.
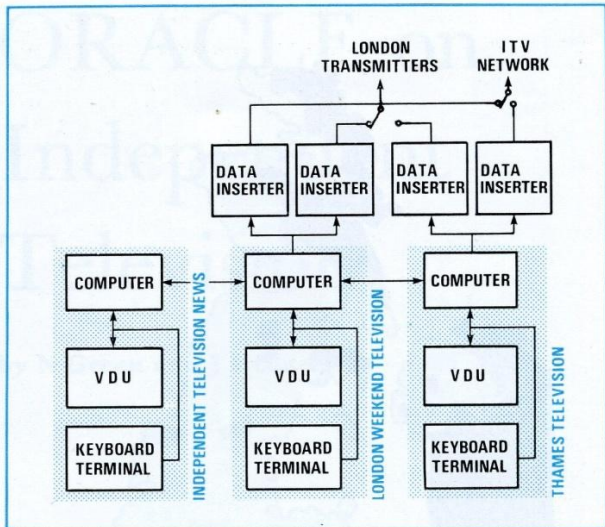
The Visual Display Unit

The visual display units (VDUs) were specially designed for the project and they display the information as the domestic viewer will see it except for the header at the top of the page which contains additional information with respect to the type of page, i.e. time coded or multipage, header suppress, etc. On the screen of the visual display unit, a blue bar is generated in place of the header information and on this bar data relevant to the page being generated is superimposed in white, thus giving the keyboard operator the information required when generating a page of data. Also displayed are the magazine and page numbers, and an indication as to whether the content of a page is new or is an amendment, the type of page, i.e. time coded or multipage, and the state of the various control bits like header suppress, etc.

The VDUs are unique in that they display not only the alpha-numeric information but also colour graphics information. They have cursors which control movement in all directions on the screen, i.e. up, down, to the left and to the right, and lines of data can be adjusted not only horizontally but vertically. When the control characters for graphics and alpha-numeric colouring are inserted, they are

not displayed, neither is the symbol for flashing. Instead, the text and/or graphics entered on the screen are displayed exactly as required. Likewise, when a newsflash or subtitle is generated, the control characters for the opening and closing of the box are not displayed, the box is merely generated in exactly the same format as is presented to the viewer.

Within each VDU there exists an interface which makes use of 240 of the 312.5 lines per field for displaying the matrix of graphic elements. To display a full row of 40 graphic elements requires 14 television scanning lines. The duration of a line is 51.2 µs and contains 40 graphic elements each occupying 1 µs.

As the electron beams in the reproducing colour cathode ray tube scan a single line of the display their intensity is modulated by signals from the interface in 167 ns periods, thus giving the colour levels for successive points of each graphic element. As the scan proceeds, so the interface switches the output from the character store to the intensity inputs of the monitor.

The information for the row currently being displayed is held in a semi-conductor scratchpad memory in the keyboard terminal and is in the form of forty 13-bit words, one word for each graphic element. The words define which characters must be displayed and which colour should be switched to the monitor at the necessary times as the scan proceeds.

The information for the full display is known as the display file and is held in the computer core memory. It is transferred to the interface one row at a time, 14 scans being performed for each row in any field. There are two scratchpad memories in the interface, one supplying data for the current 14 scan lines, the other being filled from core memory ready for the next 14 lines.

The process of taking row data from scratchpad memory and then displaying it on 14 lines is repeated 24 times for each field. For any one row twenty 16-bit words are required. These are read out of scratchpad memory for a row during the 14 line scans of the previous row.

The interface allows the computer to display 24 rows of 40 characters each. Thus, the screen is divided into 960 graphic elements and each element consists of a 6×10 matrix. A read/write memory

in the interface is used as a character generator for the user-defined characters. This memory can be loaded under program control, and any character may be changed at any time. The character set consists of 160 characters which are defined by the editorial staff. Up to four different character sets are stored and can be called up by keyboard instructions at any time.

The Data Inserters

The teletext data is inserted into the video signal by special interfaces, two to each computer, which allow asynchronous insertion of data in each of the two video feeds, one to the London transmitters and one to the ITV network. These interfaces are fed by 1 s buffers which allow the computer to carry out other tasks whilst maintaining a continuous transmission of data.

The interface identifies four of the 625 lines of a television picture and provides an output of serial data from scratchpad buffers, which have previously been filled from the computer, at a frequency of $444 \times$ line frequency. This 6.9375 MHz frequency is obtained from a voltage-controlled oscillator, within the interface, using phase-locked loop techniques to lock on to the incoming synchronising pulses. Figure 4 shows a simplified block diagram.
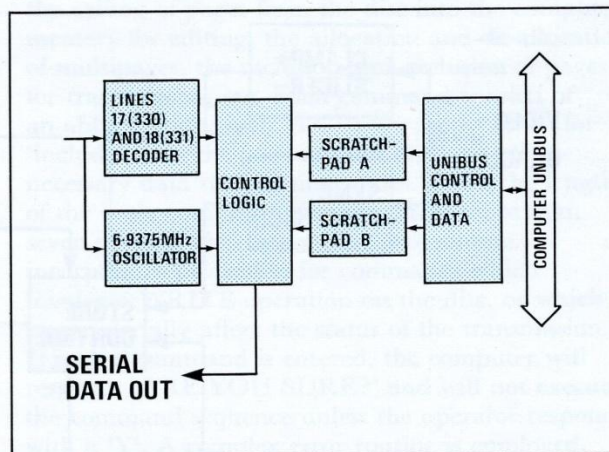
Fig. 4. Special interfaces are used for inserting teletext data into the normal television studio output waveform. Two such inserters are used at each studio centre, one for providing asynchronous insertion of data into the signal being fed to the local transmitters, the other for feeding the ITV network. As can be seen from the block diagram, the appropriate lines of field blanking are identified and on to these lines the data is read out in serial fashion, at the oscillator frequency, from the two scratchpad memories, A and B.

The television synchronising pulses fed to the interface are used as an input to the phase-locked loop oscillator circuit which produces the frequency of $444 \times$ line frequency, and as an input to a decoder circuit which identifies lines 17, 18, 330 and 331. At the beginning of line 17 scratchpad A is read out in serial fashion at the oscillator frequency, and scratchpad B is read out during line 18. Again, scratchpad A is read out during line 330 and scratchpad B during line 331. In between output cycles the computer loads the scratchpads by writing into the appropriate scratchpad load register via the output data bus.

Teletext Data Bridge

As has already been stated, a full ORACLE service is available within the London area, but in the ITV regions ORACLE can be transmitted only when a programme from either LWT or Thames is being networked.

A feature of the ITV network is that, when a regional company is originating programmes locally a stand-by network feed from the nominated contractor (either Thames or LWT) is often available. Therefore an ORACLE signal could be entering a regional

studio centre for much of the time though not being transmitted. It was this 'stand-by' feature which led to the conception of a data bridge which would be capable of taking a teletext signal from one video signal and re-timing it so that it could be re-inserted into another, asynchronous, video signal, see Fig. 5.

The video input signal is fed to a feedback clamp having a gain of 4, and also to a sync separator and processor. The sync processor produces the various gating and sampling pulses required to process the data signal. Clamped video is applied to a slicing circuit where it is sliced about the mean data amplitude. Sliced data is then applied to a clock recovery circuit consisting of a zero-crossing detector and LC tank circuit tuned to 6.9375 MHz. The output of the tank circuit is sliced to obtain the clock signal.

Data and clock pulses are then fed to an 8-bit serial-in/parallel-out shift register. The parallel outputs of the register are inspected by a framing-code detector which 'enables' a bit counter on receipt of a valid framing code. The bit counter provides a clock pulse to the data latch after every eight clock pulses and also to the read/write control
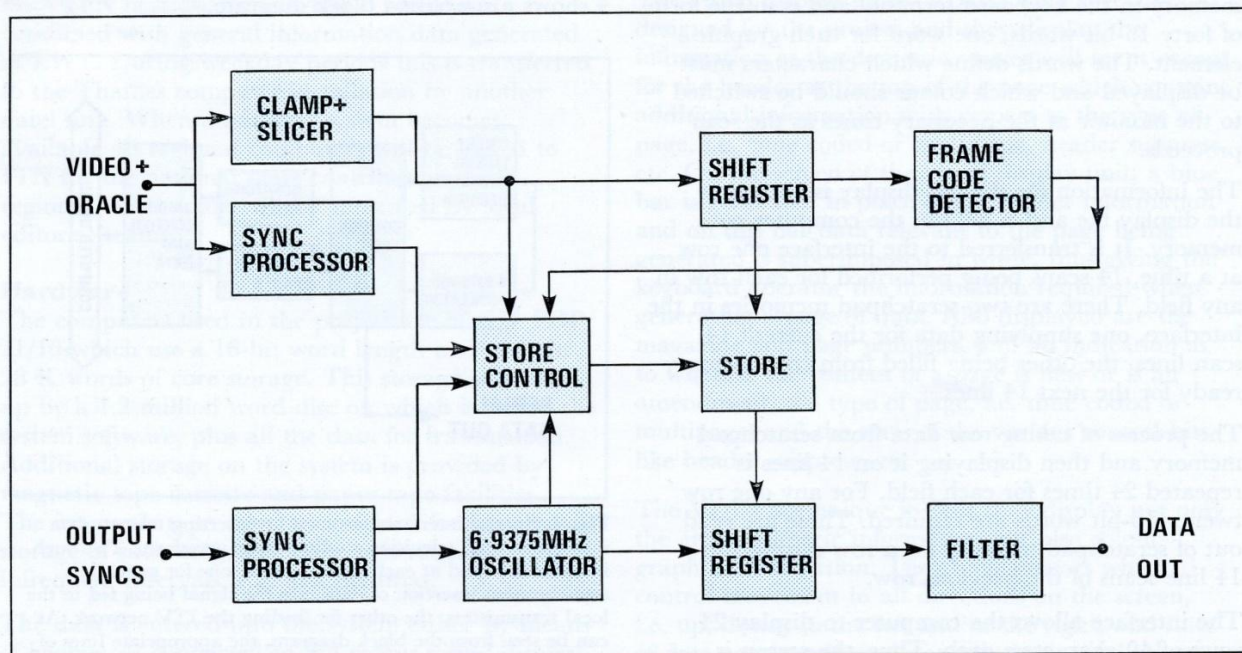

Fig. 5. A schematic diagram of a data bridge is shown. This enables teletext data to be derived from one video signal, re-timed, and re-inserted into another, asynchronous, video waveform.

circuit. Data is held in the data latch for eight clock periods during which time it is transferred to the main memory by the read/write control circuit. All of the transmitted data following the framing code is stored in the memory making a total of forty-two 8-bit words per data line. In all, four complete data lines are stored.

Composite sync pulses of the output system, usually from the interval test signal (ITS) inserter, are applied to the output sync processor which provides all the sync waveforms required to operate the output section of the bridge. An oscillator at $444 \times$ line frequency is phase locked to the line sync waveform and generates the clock signal. An adjustable counter allows timing adjustments to be made to control the start of data on the data lines.

The clock signal is applied to a bit counter which delivers clock impulses for the memory output latch, via the read/write control circuit, and load pulses for the output shift register. Run-in and framing code pulses are both fed into one section of the output shift register by the first load pulse and are then clocked out by the clock signal. After the first eight clock pulses, the first 8-bit word from memory is parallel loaded into the shift register and this is repeated every eight clock pulses until all 42 words have been loaded. The serial output of the shift register is fed via a drive amplifier to a shaping filter and then into an ITS inserter.

Progress

A prototype data bridge was built and installed at Anglia Television, in Norwich, so that a full ORACLE service could be transmitted by Anglia during the Royal Television Society Convention at Cambridge in September 1975. During this period all network programmes into Anglia were re-routed via Thames or LWT so that an ORACLE signal was always available.

The concept proved very successful and it was felt that ORACLE coverage in the regions could be greatly improved by having a number of strategically placed data bridges in the Network. The most immediate single improvement was for ORACLE to be available on schools broadcasts, which occupy several hours of morning broadcasting time. To this end a second bridge was built and installed at ATV's Studios in Birmingham. Thus, a sizeable gap in the coverage was filled by means of a single data bridge.

It is part of the ORACLE experiment for data bridges to be installed at all Programme Companies to enable the service to be always available during normal transmission hours. At a later date each of these bridges will be fitted with a test page generator, so that when no ORACLE signal is available a test page can be transmitted.

Although the bridge was designed primarily to transfer data between two asynchronous sources, care was taken to ensure that it would also function with synchronous signals and so it can be used simply as a data regenerator with a 1-field delay in the data path.

OPERATION AND APPLICATION

The ORACLE computer software has been designed specifically to allow a non-technical operator to quickly gain proficiency in operating the system. For this reason, almost all commands and functions have been kept simple and straightforward with all facilities controlled from the standard keyboard terminal.

Software

There are two basic modes of operation available to the operator. The KEYBOARD COMMAND mode is used for major command sequences such as the calling of pages from the disc into the computer memory for editing, the allocation and de-allocation of multipages, the inclusion and exclusion of pages for transmission, etc. Each command consists of an abbreviation, such as CPY for 'copy', INC for 'include', plus the page address and any other necessary data such as time codes. Thus, the length of the basic command string is rarely more than seven or eight characters. The programme incorporates protection for commands which involve a WRITE operation on the disc, or which can materially affect the status of the transmission. If such a command is entered, the computer will respond: 'ARE YOU SURE?' and will not execute the command sequence unless the operator responds with a 'Y'. A complex error routine is employed, again chiefly geared to the protection of the disc data.

When requesting a page of data from the disc into the computer memory for editing or for setting out a new page, the EDIT mode is used, and it is in this mode that almost all page data is set out and/or modified. It is operated in conjunction with the

specially designed video display interface. The page requested is displayed on the colour VDU with a flashing cursor to indicate EDIT mode, from whence the operator may amend it as desired. Facilities are available for comprehensive text manipulation in both graphic and alpha-numeric modes, all controlled from the keyboard. Character rows are displayed as they are typed, and a fresh text may be simply typed 'over' existing material, or be inserted into a row, or the existing text may be deleted as required. One very useful facility when overtyping a page of existing data is that the carriage-return can be arranged to delete all old text on any particular row to the right of the current cursor position, thus freeing the operator of the need to manually delete the old text as the work proceeds. This can be invaluable when editing news material at speed. Rows of characters can be moved left and right, or shifted up and down the page. Strings of characters may be deleted, with the remaining characters being moved to the right or left as desired. Cursor positioning is achieved by using a 'control' key in conjunction with other normal keys to give a different command function. This method is also used to generate the various control codes for providing the different colour graphics and colour alpha-numerics, subtitles, newsflash 'boxing', flashing, concealed display, and other requirements.

Both graphic and alpha-numeric material may be handled from the keyboard. Graphic designs, using the 3×2 matrix are entered by using a modified graphics code. Normally, complex graphics are not made up on the screen, except by an experienced operator, but more usually will be drawn beforehand on specially designed grids using ORACLE format. Once it has been worked out in this way, entering it into the computer is simply a matter of converting the graphics characters into the appropriate codes, and typing them in. Any final adjustment is made directly on the screen after seeing the finished design. Although there are very obvious limitations to the amount of detail which can be resolved, some quite complex maps, plans and pictorial designs have been produced, see Fig. 6.

The primary source of text input for ORACLE is an on-line keyboard terminal. However, both graphic and alpha-numeric data may be prepared off-line using standard ASCII- coded paper tape, and entered into the computer via a tape reader when convenient. A teletypewriter, usually referred to as a teletype, is used to produce off-line paper-tape material for ORACLE. Apart from simply setting out data off-line, the machine is used for generating headings for graphics and page layouts which are used time and time again. A stock of these is kept, and whichever is needed can be simply read-in from tape without affecting existing data on any particular page. The teletype also is used to produce master tapes for subtitle work, see below.

Once an ORACLE page has been designed, edited and entered in the computer core memory, several options are then open. Should it be decided that the edit is unsatisfactory it is possible at this stage to revert to the previous version of the page which existed before the edit began. If this proves to be
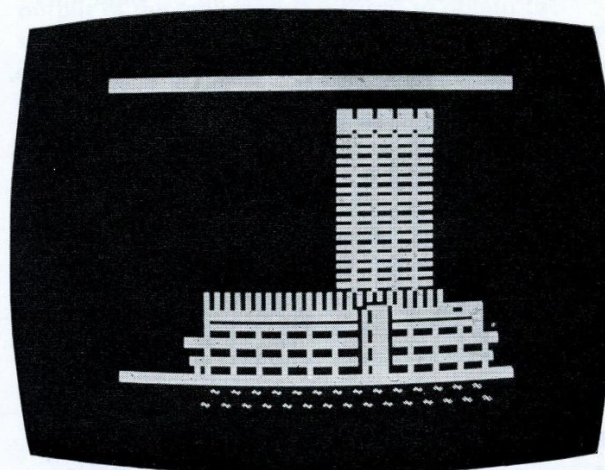

Fig. 6. In addition to displaying alpha-numeric characters, ORACLE can handle simple graphic designs. Shown here is a graphic illustration of London Weekend Television's building on the bank of the River Thames, in London.

satisfactory it can then be committed to the disc with the option of generating a hard copy print-out on the keyboard terminal. As well as being a useful aid to filing, it is likely that such hard copy will be required by the IBA as a record of transmitted ORACLE pages, in much the same way as is the sound of all ITV transmissions. A typical print-out is shown in Fig. 7. Another option is for the page to be committed to disc, but instead of the edit then being terminated, as with the other commands, the EDIT mode will in this case be maintained and the cursor remain in its last position, ready for further editing. This facility is most useful when convering fast-moving news events, such as sports

```
MON    02-AUG-76    16.27


     M4 F001    ORACLE   CL
## ## ## ## # ##
############## ##                    MOTORWAY DELAYS
###############                      AA REPORT
########################################## 401


M10
 Contra Flow System on Southbound Lanes


M40 - Between Junctions 5 and 7
 Offside Lane closures for Central
 Reservation work also Junction repairs
 on other lanes.




   See: 402 for Other Roads.
```

Fig. 7. A typical print-out of a page of ORACLE from a keyboard terminal.

results where the information on any particular page can change very quickly.

When a page has been stored in the disc, it can be made available for further editing by requesting it back into the computer memory. Once a page has been stored, the operator may schedule it for transmission either immediately or at any pre-determined time. In the latter case, the page is provided with a 'time-of-day for future transmission' using the standard 24 hour clock routine which is contained within the computer software. This facility allows the operator to attend to other work in the knowledge that a page will be transmitted on time and without further operator intervention. The facility is especially applicable in the case of news stories which carry an embargo and cannot be released before a specified time.

The normal commands for including or excluding a page or a magazine for transmission are likewise protected. At any time, the operator may request a readout of the status of all pages in the system. This includes a listing, see Fig. 8, of all pages which contain data, indicating those which are currently being transmitted, those which are scheduled for transmission at certain times, and those which form part of a multipage set.

Pages, and whole magazines containing up to 150 separate pages (including multipages), may be copied from one location to another within the ORACLE system. This is useful to editors who keep 'stock' pages with particular layouts and wish to re-use them. It also helps to keep the editorial structure of the service logical and easy to follow. The usual method, once the information has been set out in the desired format, is to enter it into a part of the computer store which is set aside for non-immediate purposes (from whence it cannot be transmitted directly) and then to copy it to another location for transmission. Pages may be over-written and included for transmission using a single command.

Pages or whole magazines may be deleted as required, but when doing this the system offers a double protection. In addition to the normal 'ARE YOU SURE?' protection, the software will not allow the deletion of a page that is included for transmission.

Multipage sets are first set out as individual pages,

Fig. 8. The key-board operator may obtain a print-out showing the status of all pages currently being transmitted, or scheduled for transmission, including those forming multipage sets. A typical example is shown here.

and subsequently linked together to form a sequential page set. The allocation and de-allocation procedure is quite versatile, and pages may be added or removed from sets at will.

In addition to standard editing and command functions, the operator has direct control over the interprocessor links between one computer system and another. Also, the status of these links may be checked at any time and any errors fed back to the operator. These, and other system faults, are printed as errors on the keyboard terminal as soon as they are detected. The system also detects and reports errors which occur as a result of sync disturbances, or of interruptions to either of the inserter interface sync feeds or the sync feed to the display interface. Faults in the modems in the interprocessor links are also reported, as are parity or checksum errors which can occur during the transmission of data.

Page Classification and Status

Within the ORACLE system there are a number of different types of page. Each type has its own editorial features, and some have limits imposed by the technical parameters which govern the status of the page.

A 'normal' page is a standard, single page of teletext. Its function is to carry fairly low-priority information such as gardening hints, health advice, etc, which is, perhaps updated less frequently than, say, news pages. Since these pages will be transmitted once per cycle, the worst-case access time, assuming the viewer selects the page immediately after it has been transmitted and therefore has to wait the maximum time before it is next transmitted, will be equal to the system cycle-time. In practice, this is not expected to greatly exceed 30 s. Other information may warrant a higher priority and so should be transmitted more frequently to avoid viewers being kept waiting. For this reason a system of page-status has been devised giving much quicker access to pages such as news, weather, travel, etc, and also to index pages.

An 'index' page as its name implies, refers to the content of other pages in the system and is given highest priority. Every 00 page in a magazine e.g. 100, 200, etc. has been allocated this status and, in addition, pages 101, 102, 201, and 202. These pages are transmitted out of sequence at intervals of 50 pages throughout the transmission cycle (though this value is not fixed and may be changed as the

experiment progresses), and the worst-case access time is therefore proportionally reduced. The penalty for such short access time on these pages is paid by slightly increasing the overall access time of the system. An index page cannot form part of a multipage.

Quite apart from indexing, information such as major news items is also deserving of priority and quick access. Therefore, news and other important information has been concentrated into magazines 1 and 2, and all pages in these magazines are transmitted twice per transmission cycle. Hence, for these pages the worst-case access time is at least halved, and the retrieval sequence of the eight magazines is 1, 2, 3, 4, 5, 1, 2, 6, 7, 8 and so on. Again, giving these pages such priority requires a slightly higher overall cycle-time for the system as a whole.

The other major type of ORACLE page is the 'multipage', or self-changing page. Here the main considerations are not so much the speed of access to information, but the nature of the information itself which is presented. A multipage is a set of pages which change in a pre-determined order, normally once per cycle. The change period can be made longer than once per cycle, but not shorter. Although the editor controls the order in which a sequence of pages is transmitted, a viewer may switch in at any point during that sequence and so see the last pages first. For this reason it is important that the viewer should be able to determine how many pages go to make up the set, and so they are numbered 'page 1 of 3', for instance.

Even with this drawback, multipages are extremely useful editorial tools in that they have far more capacity than a single normal page. They are especially useful for lists of information, such as football-league tables or lists of films currently showing where sequence is unimportant.

Most teletext decoders are fitted with a 'hold' button which, when pressed, renders the automatic multipage switching mechanism inoperative and allows the viewer to retain any selected page for detailed reading. However, since it is likely that most viewers, on selecting a multipage, will allow it to 'rotate' freely, much consideration has been given to the time for which each page should be transmitted. This parameter cannot be less than one cycle period since multipages are not transmitted

out of sequence. The cycle time on ORACLE at this stage is rarely allowed to exceed 30 s, and is normally little more than 25 s depending on the amount of information being transmitted. Therefore, it was decided that each multipage should change once per cycle, i.e. on average once every 28 s although this parameter is one which is constantly being reviewed. Having set a time, it is the responsibility of the editors to ensure that, on average, the information presented on any one multipage can be read adequately within the 28 s allowed. This imposes further limitations on the amount of information that any one page can carry, although of course, a large number of pages may be used to carry a great deal of information.

Subtitling

The use of ORACLE for subtitling television programmes is an application which can be of great importance and benefit to the deaf.

At the present time, the few programmes which are especially captioned to assist deaf people are made by the simple expedient of adding to the picture either superimposed or inlaid subtitles. The main disadvantages of this are that all viewers, deaf or otherwise, see the subtitled version of the programme and, because the subtitles have to be recorded directly on to the programme tape, this precludes any flexibility or changes after the programme has been produced.

By using the 'box' mode of ORACLE in conjunction with appropriate computer software it is possible to provide the option of subtitles with standard programmes. By selecting a particular ORACLE page, a deaf person could have subtitles for a programme displayed in a box on the picture. Any person, not requiring subtitles, would have no need to select the subtitled page and therefore would watch the programme as normal.

A basic mechanism by which ORACLE subtitling can be produced is as follows. The programme video tape has recorded on its control track a continuous tape time (in SMPTE VTR time code). The subtitles, in boxed ORACLE format, are prepared off-line using a standard teletype machine to generate a paper-tape. They are then stored in the computer disc with a time cue for each subtitle. On transmitting the programme, the time codes from the video tape are compared with those of the subtitle stored in the computer, and when they are

the same the normal ORACLE transmission sequence is momentarily interrupted and the subtitle transmitted. The normal sequence of transmission is then resumed until the next subtitle is cued, and so on.

By this means a much greater degree of flexibility is possible when subtitling a programme. No thought need be given to the subtitling at the production stage, and the subtitles themselves can be prepared and amended as standard ORACLE pages right up until the time of transmission. Even the times at which the subtitles are inserted during the programme can be varied. ORACLE subtitles can utilise the normal facilities in the box mode e.g. colours, flashing etc., but it is felt that to be of real value, double-height characters (see below) should be employed to assist legibility. Subtitles will also probably be limited to one or two rows per caption to minimise the amount of television picture that is obscured.

Although a number of experimental programmes employing this method of subtitling have been produced, much work is still necessary to decide such parameters as the optimum format, upper and lower case characters and the optimum time for displaying each subtitle, etc. Further experiments will be made with the assistance of those concerned with aiding the deaf.

Programmed Learning

As well as providing teachers' notes to supplement normal educational television programmes, ORACLE has been used for a short experimental period as a more direct educational tool. This has been achieved in co-operation with the Educational Computer Centre of the London borough of Havering which has a programme of computer-managed learning for pupils in the borough. ORACLE pages have been used as a cheaper and far more readily 'updateable' alternative to paper in providing information about individual lessons, and providing pupils with notes and diagrams during science experiments. The Havering computer produces the instructional text which is then transferred to the ORACLE system. During lessons the pages of notes are displayed on a standard ORACLE receiver. On completion of lessons the answer sheets from pupils are assessed by Havering's computer which up-dates the profiles of individual students and sets work for the next lesson. Figure 9 illustrates this.
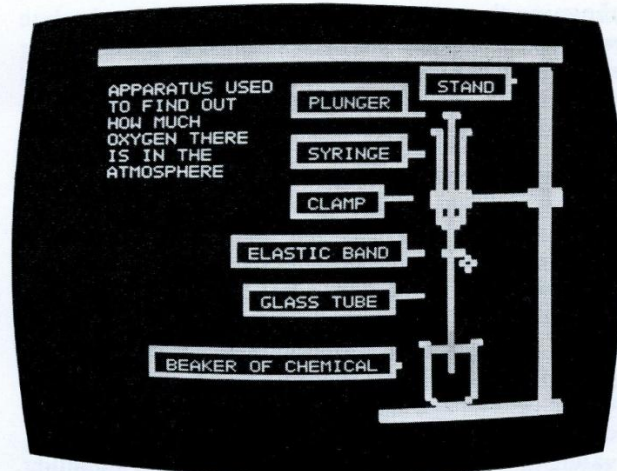
Fig. 9. Educational television programmes, particularly those for schools, can be greatly assisted by means of ORACLE. Pages of instructional notes can be transmitted which may include text and simple diagrams of the type shown.

Improvements to Teletext

The ITCA engineering and editorial teams have been experimenting with several improvements to the teletext specification. Most notable of these have been:

a) *The 'Hold' Character Mode*

One of the more recent developments of the ORACLE system has been the ability to transmit graphic designs which allow a change of colour from one graphics symbol to another without a surrounding black band. This has been achieved by the use of a new graphics mode ('hold') whereby, when a change of graphics colour in a row is required, the decoder is instructed to repeat the previous graphics character and colour in the space occupied by the new graphics colour *control* character. The result is that a clean change from colour to colour is now possible horizontally as well as vertically. The introduction of this 'hold' mode has enabled the use of more complex colour schemes in graphic designs, maps, plans, charts, etc, see Figs. 10 and 11.

b) *Double-height Characters*

Research into the reading of alpha-numeric characters on the screen in certain situations, e.g. school-rooms, has shown that legibility of ORACLE pages can be vastly improved by

Fig. 10. Until recently it has not been possible to display a change of colour during a row of characters without leaving a blank space where the change occurs, . . .

Fig. 11. . . . but by means of the newly developed graphic 'hold' mode of operation, the last character prior to the new instruction is held in the memory and repeated, thereby closing the gap.

displaying characters with twice the normal height but normal width (i.e. 28 television lines high rather than the 14-line height of normal text). Therefore, again in response to a control character, a decoder can be instructed to display any row of text in double-height characters as shown in Fig. 12. The editorial uses of this type of display will be found chiefly in the areas of education and in the subtitling of television programmes. Whereas ORACLE

characters of standard size would be almost invisible to any pupil sitting at the back of the class-room, the use of double-height characters will make ORACLE a much more viable and useful tool to the educationalist.

Editorial use has also been made of the insertion of one or two rows of double-height characters in a page of text of otherwise standard height. This has a great impact on the viewer without the editors having to use large headlines made up from graphic elements. Such elements occupy an unnecessarily large number of lines on the page, besides reducing the number of letters in the headline.
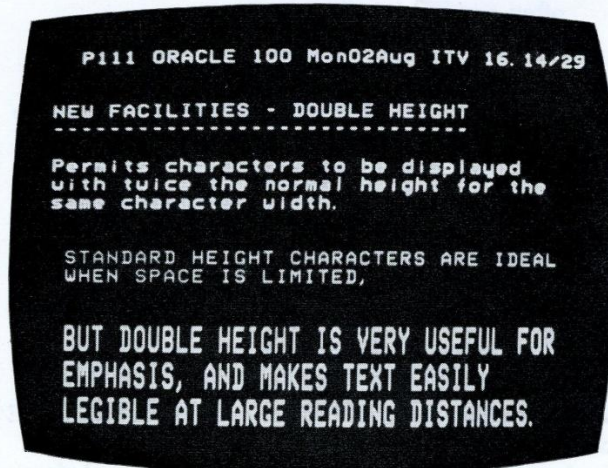


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P111 ORACLE 100 Mon02Aug ITV 16.14/29

NEW FACILITIES - DOUBLE HEIGHT
------------------------------
Permits characters to be displayed
with twice the normal height for the
same character width.

STANDARD HEIGHT CHARACTERS ARE IDEAL
WHEN SPACE IS LIMITED,

BUT DOUBLE HEIGHT IS VERY USEFUL FOR
EMPHASIS, AND MAKES TEXT EASILY
LEGIBLE AT LARGE READING DISTANCES.
```

Fig. 12. In certain viewing conditions, notably school class-rooms, etc., the legibility of the alpha-numeric display can be greatly improved by the use of double-height characters. This is illustrated in the accompanying photograph.

ORACLE as an Editorial Medium

At present there are at ITN one editor, two journalists and a keyboard operator; and at LWT one supervisory editor, an editor, a researcher and two keyboard operators. This editorial staff has come to regard ORACLE as filling a vital gap between, on the one hand, the relatively fast coverage of major news events given by radio and television and, on the other, the more probing, in-depth journalism offered by a newspaper.

There can be no doubt that radio and television bring news to the public fast, but this often involves the interruption of normal programming; ORACLE on the other hand is available as and when the viewer wants it. Indeed, ORACLE can be superimposed on the normal television picture if

preferred. The instant recall of news stories offered by ORACLE implies that a story or sports result which was inserted during a morning, say, will be available to the viewer throughout the rest of the day, updated as required.

However up-to-the-minute a newspaper story is when it goes to press, it can be significantly out of date by the time the paper reaches the news-stands. But ORACLE pages can be updated immediately information is received by the editors.

With these obvious advantages, ORACLE poses a challenge to its editorial team. What kind of information should be carried by the service? In what form should it be presented? How much information could be carried on each page? News coverage is perhaps the most obvious field for exploiting such a system, and in many ways the most challenging. One full page of ORACLE data, adequately spaced to assist legibility would be equivalent to possibly only one or two column-inches in a newspaper. Consequently, journalists at ITN were faced with the task of condensing and summarising news in its most rudimentary form, extracting the main elements of each story and presenting them as briefly and concisely as possible. The policy adopted for news on ORACLE involves the use of a single page of 'headline'—found by reference to the master index—giving a one or two line 'leader' for a story followed by the relevant page number. The viewer then selects whichever story most interests him in the normal manner.

Several different categories of news are available. At present, in addition to the normal home news and world news pages, coverage of sport and finance is provided. Details of sports fixtures also are given, and these can be updated at very short notice to include details of, say, football matches cancelled due to weather, etc. This kind of information would probably arrive too late to be of real value to a newspaper. Sports results are also available, and these may be used in conjunction with the normal sports coverage on television with the advantage that the results would remain on ORACLE long after ordinary coverage of the events had finished.

So far as finance is concerned, FT index, stock market reports, company reports, the pound, all seem to lend themselves to presentation via the ORACLE medium, although the format limits the number of stock market prices that can be carried.

In addition to normal single pages, multipages are used where any long sequence of information is needed and where the entry point of the viewer into the sequence is non-critical. Multipages also allow the combining of two or more subjects under a single index heading, e.g. stock market reports and the FT index. This can assist the logical presentation of material and can also save access time, since a multipage set counts as only a single page of access, however long the sequence.

Perhaps one of the most useful and popular features of ORACLE is the 'newsflash' facility. Having selected the newsflash page (by reference to the index), a viewer can continue watching the normal television programme, confident that, should a major news event occur, brief details will immediately be flashed on the screen. The newsflash makes use of the 'box' mode, the text being displayed in a black area inlaid on the picture. The newsflash would normally refer to another page containing further information. The viewer can then either re-select or cancel the newsflash. No further display of the newsflash page will occur until a fresh newsflash is transmitted.

When not being used for its newsflash purpose, the same page may be utilised for covering sports events ('scoreflash') or running scores for quiz shows—indeed, anything for which the requirements are a small amount of information constantly subject to revision.

In all, about 60 pages of ORACLE at present are devoted entirely to hard-news coverage. In addition to news, the range of uses to which ORACLE can be put varies enormously and extends from weather information to astronomy, from gardening to metrication. Information is arranged in categories which are listed in the master-index (page 100). Each category has a sub-index (a priority page), and the subsequent information is presented on pages following numerically from the index page, thus rendering the layout easy to follow. Wherever possible, categories are combined under single headings; this helps to reduce access time because the viewer is not obliged to wander from index to sub-index in seeking the required page numbers.

As regards actual editorial use of the system, the possibilities have really only just begun to be appreciated. However, the following list gives an idea of some of the uses to which the system can be put:

NEWS: home and foreign.

SPORT: fixtures and results.

FINANCE: news, company reports, FT index, etc.

WEATHER INFORMATION: both national and local, plus resorts such as the sunshine league, and the long-range forecasting.

TRAVEL INFORMATION: for road, rail and sea. An up-to-the-minute service can be given here.

FAMILY MAGAZINE: a very wide topic which embraces hobbies, pastimes, home hints, recipes, shopping offers, etc.

TELEVISION PROGRAMMES: a listing of the evening programmes. This can be kept up-to-date with any last minute changes which often occur. Linked with—

PROGRAMME-RELATED INFORMATION: which provides back-up to normal television programming; for example, summaries of plays, cast lists for films, details of set books for adult education, etc.

LOCAL AFFAIRS: is a local news digest, currently confined to London and the Home Counties.

EDUCATION: is an important area since ORACLE could be an extremely useful aid to the teacher. To date teachers' notes, diagrams, etc. have all been subjects for experiment.

These are only a few of the subjects which ORACLE can cover—a glance at the index from week to week will show how often new information is being added as part of the continuing editorial experiment.

Advertising

Commercial usage of ORACLE demands other considerations. For example, the viewer must be made to want to turn to an ORACLE advertisement, whereas in normal television advertising there are regular commercial breaks. This and other related matters are all currently under consideration but, although some experimental advertising has been tried in several forms, no final conclusions have been reached as to the ultimate nature of ORACLE's commercial content.

The Future

Although still a medium in its infancy ORACLE has come a very long way in a remarkably short time. The newsman regards it as an instant newspaper, the educationalist as a computer-controlled textbook,

the housewife as a convenient source of useful household information.

And although most of the technical parameters have now been established, the editorial considerations are still quite fluid. There are few limits to the uses to which ORACLE may conceivably be put in the years ahead, but whether it will turn out to be the first stage in that long-awaited science-fiction dream of the home computer terminal, remains to be seen.

The experimental programming of ORACLE has involved principally the three ITCA organisations London Weekend Television, Thames Television and Independent Television News, under the

guidance of a Management Board chaired by Mr G A Cooper of Thames Television. The system described was designed by ITCA engineers and built within seven months. Since installation, the system has achieved an efficiency of some 99.9% of on-air time.

J L E BALDWIN, BSc, M Inst P, MRTS, and Freeman of the City of London, has been working in television since joining Rank Cintel in 1950. After 14 years he moved to Peto Scott Limited (part of the Philips Group) becoming Chief Engineer. In 1967 he joined the Authority as head of the Video and Colour Section of the Experimental & Development Department.
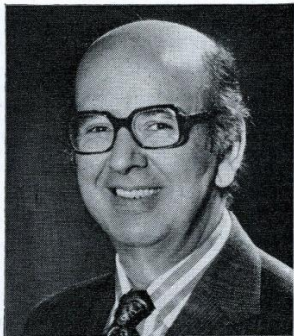
In 1975, he was awarded the David Sarnoff Gold Medal of the Society of Motion Picture & Television Engineers for his personal contribution as leader of the team which developed DICE.

Sampling Frequencies for Digital Coding of Television Signals

by J L E Baldwin

Synopsis

In choosing the sampling rate for a digital colour television system, account has to be taken of the line frequency. the subcarrier frequency, and the system of colour coding. Accordingly, there may be advantages in digitising the composite colour signal, or in digitally coding the luminance and chrominance components separately, and in either case there are several possible alternatives.

Standards conversion is another factor deserving consideration. To facilitate the design of a practical interface between one standard and another, the sampling rates for the two systems should be precisely related.

Introduction

If a single standard could be adopted for the digital transmission of all 625-line television signals, then obviously the international exchange of programmes within Europe, where pictures are originated both in PAL and SECAM, would be noticeably easier than at present.

The inherent nature of SECAM, which uses frequency modulation for carrying chrominance information, requires that the luminance and chrominance components be separated, and the chrominance demodulated, before any fading or mixing operation can be performed. It follows that a digital system in which the luminance and chrominance components are individually coded would have significant advantages in countries using SECAM.

On the other hand, PAL signals are invariably faded and mixed as coded composite signals, and no provision is made in, for example, vision mixers to operate separately on the luminance and chrominance components. In this case a system which digitally codes the composite PAL signal would be advantageous.

It has been recommended (by EBU Working Party C—*Digital Coding of Sound and Vision*) that the signal impairment produced by four pairs of digital coders and decoders in cascade should not be worse than grade 4.5 on the new CCIR 5-point scale[1]. This grade corresponds to a situation in which half the total number of observers can detect an impairment while the remainder are unable to do so. For these subjective tests the picture should be critical but nevertheless representative of material normally transmitted. The choice of four coder-decoder pairs (codecs) in cascade recognises that mixed analogue and digital paths will persist for a significant period, particularly during international transmissions.

The change to digital operation is expected to take place over a long period, perhaps 10 to 20 years,

unless there is a very significant financial advantage to be gained from it being more rapid. It follows that the digital signals must be very compatible with the present colour-coded analogue signals so that inter-mixed systems can co-exist during the extended change-over period. Also, that the interfaces between the analogue and digital parts of the system must cause negligible impairment, be reliable, drift-free, and yet be of reasonable cost.

Obviously, at some time in the future, possibly in conjunction with direct broadcasting from satellites, it might happen that the broadcast television signal will be radiated in digital form. However, in this article it is assumed that the radiated broadcast television signal will remain in the same form as that used at present.

Sampling Requirements

In general, it would be desirable if the sampling frequency were simply related to line frequency in that this simplifies the operations of digital blanking and sync pulse addition. Ideally, it should be an integral multiple of line frequency, see Fig. 1, so
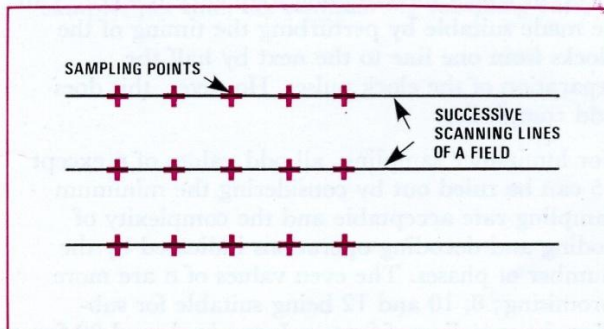

Fig. 1. When the sampling rate is an integral multiple of line frequency, kf_L, the samples are arranged on the raster in equispaced vertical columns.

that under these conditions only one set of blanking edge coefficients and one set of sync pulse edges need be stored in a read-only memory. However, in some systems, e.g. those using sub-Nyquist techniques, it is desirable to use a sampling frequency equal to $(k+\frac{1}{2}) \times$ line frequency, where k is an integer, see Fig. 2. This has been used also for above-Nyquist sampling of NTSC signals. In these circumstances it is necessary to store two sets of blanking coefficients and sync edges which are used on alternate lines. These relationships between line and sampling frequencies could be used with component coding.
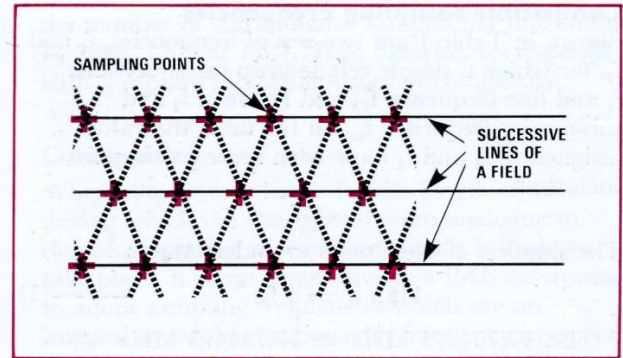

Fig. 2. Sampling at a rate equal to an odd multiple of half-line frequency, $(k+\frac{1}{2})$ f_L, causes the samples to occur along symmetrical sloping lines.

When, however, a composite signal of the PAL or NTSC type is digitally coded it becomes very desirable to sample at a frequency simply related to sub-carrier, e.g. $3 \times$ sub-carrier frequency. This is not so much to minimise impairments resulting from sampling and quantisation, but is much more for reasons of differential coding prediction, error concealment, the use of synchronisers for intentional mis-alignment of pictures to facilitate split screens, and particularly to meet the requirements of digital colour coders and decoders.

Surprisingly, it becomes even more important to use a sampling frequency simply related to sub-carrier if component coding is used in a PAL environment. This results from the need to digitally PAL-encode a signal prior to:

    i a digital i.f. modulator in a transmitter,

    ii an analogue video-tape recorder,

    iii an analogue terrestrial or satellite link.

It could be argued that (ii) and (iii) above could be achieved by converting the three components to analogue form and coding these together in a special PAL coder. However, the converse requirement, of separating the PAL signal into its luminance and colour-difference components without significant impairment, would require complex comb-filtering techniques which appear impossible to realise in a stable form using analogue methods. The required stability can be realised by making use of digital techniques, but to be economically viable the sampling frequency must be simply related to sub-carrier.

Compatible Sampling Frequencies

Shown in Table 1 are two sets of frequencies, f_1 and f_2, for which a simple relationship exists between f_1 and line frequency f_L, and between f_2 and sub-carrier frequency f_{sc}. In the table the values assigned to f_1 and f_2 have been arranged in pairs such that

$$f_1 \simeq f_2.$$

The simplest of these pairs to understand is

$$1135\, f_L \simeq 4\, f_{sc} \qquad \text{————(1)}$$

i.e. 17.734375 MHz $\simeq 17.734475$ MHz

The difference of 100 Hz causes a slip of half a period of one cycle of sub-carrier during a field. This slip is constant for all pairs of frequencies in the two sets.

If a signal is converted from a sampling rate based on line frequency, to the corresponding rate based on sub-carrier frequency, then, during the period of each field there occurs a horizontal displacement between the top and the bottom of a picture of about 1/500 of the picture width. Thus, vertical lines are represented at an angle of less than $0.2°$ from their correct position. This small divergence is insignificant. However, a change of phase of sampling equivalent to half a cycle of sub-carrier has to occur during each field blanking interval to prevent the picture from progressively moving sideways.

In the case under consideration, the number of samples per line is 1135. Unfortunately this has only two factors, 5 and 227; hence, expression (1) can be divided by 5 or by 227 yielding respectively

$$227\, f_L \simeq 0.8\, f_{sc} \qquad \text{————(2)}$$

and

$$5\, f_L \simeq \frac{4}{227}\, f_{sc} \qquad \text{————(3)}$$

This second result has a relationship with sub-carrier which is much too complex; it would be necessary to generate 227 different sine and cosine values in each digital colour coder, or decoder, and would also require complex multipliers. Therefore, it need not be considered further. For certain purposes, e.g. the sampling of SECAM colour-difference signals, a sampling frequency equal to $(k' \pm \frac{1}{4})\, f_L$ is desirable, where k' is an integer.

All frequencies of interest in these series can therefore be found from

$$f_1 = \frac{227}{4}\, nf_L \qquad \text{and} \qquad f_2 = 0.2\, nf_{sc}$$

and these are the frequencies listed in Table 1. The last column in the table shows the number of different phases of the sampling instants before there is a repetition, using sub-carrier as a reference, but also allows for a half period of sub-carrier re-timing during the field group. This gives some indication of the degree of complexity of a digital PAL coder or decoder operating at this sampling rate for the luminance components. It assumes that the chrominance sampling rate for the compatible component-coded signals is chosen either such that it has the same number of phases or that it is a factor of the number of luminance phases. If the number of phases is divisible by 3 or 4 some simplification is possible.

Some frequencies are more suitable than others for sub-Nyquist sampling. Preferably, they should normally be an odd multiple of half line frequency, but this is not essential. For example, the case of $n=8$, in which the sampling frequency is $454\, f_L$, can be made suitable by perturbing the timing of the clocks from one line to the next by half the separation of the clock pulses. However, this does add complexity.

For luminance sampling, all odd values of n except 15 can be ruled out by considering the minimum sampling rate acceptable and the complexity of coding and decoding operations indicated by the number of phases. The even values of n are more promising; 8, 10 and 12 being suitable for sub-Nyquist sampling of System I standard, and 20 for sampling at above-Nyquist rates. The additional complexity for $n=12$, arising from the need to perturb the clocks from one line to the next and the rather high sampling frequency for a system that is marginally sub-Nyquist, tends to make it less acceptable. However, it may be satisfactory to consider this system to be above the Nyquist rate since the level of any frequency which would produce aliasing products would tend to be low and would cause frequencies which have a low visibility.

When allowance is made for the difficulties of digital coding or decoding of a PAL signal, it becomes obvious that the best sub-Nyquist case corresponds to $n=10$, equivalent to sampling at twice the sub-carrier frequency. In addition, this has been shown by the BBC to be capable of

operating satisfactorily for PAL coded signals through a single codec, but it might be marginal for 4 codecs in cascade. For sampling above the Nyquist rate the cases corresponding to n$=15$ and n$=20$, i.e. sampling at 3 or 4$\times$sub-carrier frequency, seem to be natural choices and, considering the bit-rate, the lower is preferred. However, $4f_{sc}$ sampling rate may have a particular relevance as an interim standard in converting to the sub-Nyquist sampling rate of $2f_{sc}$.

For component coding, the choice of the more suitable chrominance sampling rates depends to a certain extent on the sampling rate adopted for luminance. If there are $567\frac{1}{2}$ luminance samples per line, i.e. nominal $2f_{sc}$ sampling rate, then possible numbers of chrominance samples per line could be $283\frac{3}{4}$, 227, $170\frac{1}{4}$ or $113\frac{1}{2}$ in a rapidly increasing order of complexity. In particular, the lowest number would cause great problems due to the filtering requirements associated with sub-Nyquist sampling, and it may be that a better choice would be $170\frac{1}{4}$ samples per line. For $851\frac{1}{4}$ luminance samples per line, i.e. nominal $3f_{sc}$ sampling rate,

the number of chrominance samples per line could be $283\frac{3}{4}$, $170\frac{1}{4}$ or $113\frac{1}{2}$. This, likewise, corresponds with a rapidly increasing order of complexity.

Conclusion

When allowance is made for the length of time during which the changeover from analogue to digital processing of television signals is likely to take place, it seems imperative in a PAL environment to adopt sampling frequencies which are an integral multiple of sub-carrier frequency irrespective of whether composite or component coding is used. Provided that those countries using SECAM adopt $851\frac{1}{4}$ or $567\frac{1}{2}$ luminance samples per line and $283\frac{3}{4}$, 227, $170\frac{1}{4}$ or $113\frac{1}{2}$ chrominance samples per line it would, in principle, appear possible to provide a digital interface between these and PAL standards, for either direction of transmission.

Reference
1. 'Method for the Subjective Assessment of the Quality of Television Pictures', *CCIR Recommendation 500*, XIIIth Plenary Assembly, Geneva 1974.

Table 1

COMPATIBLE SAMPLING FREQUENCIES FOR COMPONENT AND COMPOSITE DIGITAL CODING.

n	NUMBER OF SAMPLES PER LINE	f_1 (MHz)	NUMBER OF SAMPLES PER CYCLE OF SUB-CARRIER	f_2 (MHz)	$f_2 - f_1$ (Hz)	NUMBER OF PHASES
1	$56\frac{3}{4}$	0.886 718 75	0.2	0.886 723 75	5	2
2†	$113\frac{1}{2}$	1.773 437 5	0.4	1.773 447 5	10	2
3†	$170\frac{1}{4}$	2.660 156 25	0.6	2.660 171 25	15	6
4†	227	3.546 875	0.8	3.546 895	20	4
5†	$283\frac{3}{4}$	4.433 593 75	1.0	4.433 618 75	25	2
6	$340\frac{1}{2}$	5.320 312 5	1.2	5.320 342 5	30	6
7	$397\frac{1}{4}$	6.207 031 25	1.4	6.207 066 25	35	14
8*	454	7.093 750	1.6	7.093 790	40	8
9	$510\frac{3}{4}$	7.980 468 75	1.8	7.980 513 75	45	18
10*	$567\frac{1}{2}$	8.867 187 5	2.0	8.867 237 5	50	2
11	$624\frac{1}{4}$	9.753 906 25	2.2	9.753 961 25	55	22
12*	681	10.640 625	2.4	10.640 685	60	12
13	$737\frac{3}{4}$	11.527 343 75	2.6	11.527 408 75	65	26
14	$794\frac{1}{4}$	12.414 062 5	2.8	12.414 132 5	70	14
15*	$851\frac{1}{4}$	13.300 781 25	3.0	13.300 856 25	75	6
16	908	14.187 500	3.2	14.187 580	80	16
17	$964\frac{3}{4}$	15.074 218 75	3.4	15.074 303 75	85	34
18	$1021\frac{1}{2}$	15.960 937 5	3.6	15.961 027 5	90	18
19	$1078\frac{1}{4}$	16.847 656 25	3.8	16.847 751 25	95	38
20*	1135	17.734 375	4.0	17.734 475	100	4

*Potentially useful for sampling luminance or PAL composite signals.

†Potentially useful for chrominance sampling.

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Digital Transmission Techniques

by G M Drury

Synopsis

Digital signals are returning to take the dominant role they once had in the early days of telegraphy. The technology and techniques are now available simultaneously to enable great advances to be made in the design of high capacity trunk transmission systems offering technical and economic performance at least equal to that of current analogue systems.

Whilst great strides have been made with analogue transmission of television signals in recent years, there are some clear advantages in adopting digital methods. For instance, differential phase and gain distortion cannot occur in a digital system, no matter how long the transmission link may be. Obviously in a hybrid system distortion will continue to be introduced in the analogue sections. The IBA has carried out preliminary experimental work on digital transmission links with a view to studying their feasibility.

In this article a brief review is given of the many aspects of digital transmission systems, indicating not only the general principles, but also solutions to specific design problems. An attempt is also made to outline the true historical perspective of digital transmission which has become confused by reason of the accepted use of analogue techniques during the recent past.

Introduction

Until recently, the majority of telecommunication transmission systems have been analogue. By this is meant that the information to be transmitted is represented by a signal parameter, such as amplitude, phase or frequency, which is caused to vary continuously in sympathy with variations in the desired information. Analogue techniques have not always held this dominant position, for, in the early days of signalling, telegraphy was paramount. Telegraphy is essentially digital because a voltage switched on and off at the transmitter causes the receiver to assume a limited number of discrete states identifiable with particular messages. The Morse code is a well-known example of an early telegraphic or digital coding scheme.

There are many reasons why the early digital techniques did not maintain ascendancy, the most important of these being that, at the time when the telecommunication networks were expanding and demanding high capacity links, the available digital technology was insufficiently developed. The principal electronic device available was the triode valve (invented c. 1906) and at this time was better suited to continuous, low-bandwidth analogue signals than to ON/OFF mode digital signals which required high switching speeds, and hence a wider bandwidth.

Unlike the thermionic valve, the transistor (invented c. 1947) is a nearly ideal, high-speed switch, and is the basis for modern high-speed integrated logic circuits necessary for high capacity digital transmission schemes. It could be argued that this technology enables a return to the natural evolution of digital techniques, which were prematurely interrupted by the failure of contemporary technology

to meet the demands of early transmission networks, and resulted in the expedient of analogue techniques.

Current Trends

The British Post Office has expressed a firm commitment to the adoption of digital techniques in the trunk transmission network. The reasons stated for this are that, due to the clear economic advantages that digital techniques have for telephony signalling and switching arrangements, it follows that digital transmission schemes gain an advantage over analogue ones.

The commitment has already been demonstrated by the planning of widespread installations for digital transmission systems in the exchange/exchange connection network. Many 24-channel telephony systems operating at 1536 kbit/s have been installed and are being superseded by the internationally agreed standard systems operating at 2048 kbit/s and providing 30 telephony channels. There are also proposals for the use of 8448 kbit/s (120 channels) for exchange/exchange trunk systems, and for approximately 140 Mbit/s as the basis of high capacity inter-city trunk systems. Initially 120 Mbit/s systems will be used, but 140 Mbit/s will become standard after a few years.

In addition to this interest in terrestrial transmission links, the International Telecommunications Satellite Consortium (INTELSAT) and the European Space Agency (ESA) have shown interest in digital techniques for the rapidly growing world-wide communications satellite network. Preference has emerged for 60 Mbit/s and 180 Mbit/s; INTELSAT has chosen the former, and ESA have chosen both.

The evolution of the modern telecommunication transmission network has been based on the requirements of telephony, so that broadcasters who make use of this network tend to be at a disadvantage. This situation could prevail in the digital era unless serious interest is taken in the development of equipment which is equally suited to the needs of sound and television signals as used in broadcasting. With this object in mind the transmission network provides an early opportunity to make inroads into the present system without the need for major changes at studio centres and without prejudicing future studio development.

Digital Transmission Fundamentals

A complete and thorough evaluation of the merits of digital transmission is beyond the scope of this article. However, the following points summarise the basic advantages of digital techniques:

1) a controllable level of impairment by direct design,

2) the precision of the system is inherent, thus obviating the need for adjustments, i.e. gives high stability,

3) programme quality throughout a network is practically constant, i.e. consistency of performance,

4) the digital format is flexible,

5) custom designed integrated circuit technology affords greater overall reliability.

The function of digital transmission is that of carrying digitally encoded signals from one point to another. The basic process is simply that of propagating pulses of energy along a transmission path in such a way that they may be recognised at the receiver. The fundamental theory of this process is well established and may be found in many modern textbooks dealing with data transmission[1].

All digital transmission links are composed of nominally identical sections, each one of which is, in principle, independent of all others, see Fig. 1. The output signal produced by a particular regenerator is passed to the transmission medium, a coaxial cable in the example of Fig. 1, wherein it is propagated until weakened to the extent that pulse regeneration is essential. The design of the link as a whole is based on maximising the distance travelled between regenerators while minimising information impairment.

Within each regenerator there must be:

i an amplifier/equaliser to restore the weak received pulse to a suitable shape for further processing,

ii one or more amplitude discriminators for determining the presence or absence of a pulse at particular instants of time as determined by the pulse repetition frequency,

iii a timing extractor which generates control signals to govern the timing of the amplitude discrimination and output pulse generation,
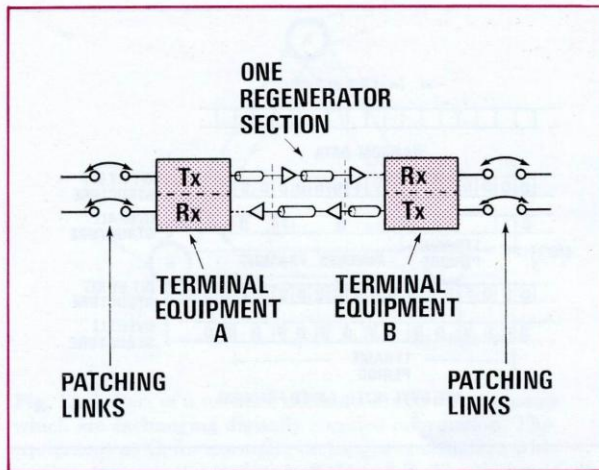
iv some output device for driving the next link section.

Fig. 1. A digital transmission link indicating the way in which the route distance between terminals A and B is divided into sections, each one of which functions as an independent unit. The regenerators restore the received weak and distorted pulses to their original state, thus removing any impairment caused by the cable lengths between the regenerators. This arrangement conveys pulse streams between A and B and the impairments to these streams are occasional incorrect pulse regeneration (errors) and timing phase modulation or jitter. Both of these impairments are due to the regenerator mechanisms and cannot be removed completely. An explanation of these impairments is given in the text.

The impairments introduced by digital transmission may be traced directly to the processes occurring in regenerators. When amplitude discrimination is incorrect, digital errors occur; when simple timing extraction is employed, phase modulation or jitter is introduced in the regenerated pulse streams.

Although digital transmission systems are, in principle, ideal systems and can be engineered to produce virtually impairment-free transmission, in practice this is not economically possible. The design of practical links thus approaches a performance standard which is improved only at an unacceptable economic penalty.

Digit Errors

The parameters of interest in assessing performance standards include a measure of the accuracy with which the amplitude discriminators at the regenerators can determine the content of a digit stream. A bit-by-bit comparison of the transmitted and received streams will reveal occasional discrepancies, or errors, when bits are wrongly reconstructed. The proportion of such bits in a given total number of examined bits is a measure of error rate or, more precisely, error probability. It is relatively easy to show (see Reference 1) that the mechanism of error generation is statistical and that the probability of an error occurring can be predicted. In the short term, error probability is only a guide to the rate of error generation, but in the long term, i.e. if a large number of bits are examined, a more accurate measure of error generation is obtained.

The statistical distribution of errors varies with the kind of impairment causing the errors, and with the further digital processing which occurs before the binary data stream is recovered for examination. This means that, for example, the thermal noise predominance in coaxial cable systems produces error statistics different from those found in radio-relay systems where interference, noise, and the effects of propagation fading modify the error generation process.

By incorporating parity check bits in the digital streams, error detection and correction can be achieved at the expense of true information capacity; a 'trade-off' must be achieved between the necessity for error control and loss of information capacity.

Jitter

A second important impairment parameter in conventional digital transmission systems is jitter. Since the regenerators are usually self-timed, i.e. they derive their timing clock pulses from the incoming digit-stream, the recovered clock waveform has some spurious modulations in amplitude and phase due to the digit patterns. The amplitude modulation may be removed by passing the clock waveform through a limiter before it is used. The timing modulation cannot be removed completely without further impairment of the error generation process, so that this timing modulation, or jitter, can be controlled only so far during clock extraction. Since the same basic modulation occurs at each regenerator, there is strong correlation between the jitter introduced by each regenerator; hence, at the end of a chain of such regenerators, the jitter will build up. The manner in which this occurs is well-understood and is thus predictable.

Occasionally, over a long transmission path, jitter reduction will be required because there is no upper

limit to the amount of jitter which can accrue. A jitter reduction unit employs a very high-Q clock extractor and a short data store, so that data is read into the store using a conventional 'jittery' clock and read out again using the highly stabilised clock.

Another method of jitter control is that of breaking up those digital patterns which cause large amounts of jitter. The technique of scrambling is a common method, as is pattern transformation at certain regenerators. The latter technique reduces the correlation between jitter introduced at successive regenerations, thus reducing jitter overall.

Digit Stream Organisation

The simplest digital information processing format is binary, since signal handling circuits are simplest when only two states of conduction are required. This means that the binary symbol or digit (abbreviated to 'bit') becomes the unit of information quantity, and the capability of a system for handling information in digital form is measured in bits/second, i.e. the rate at which information is handled.

If certain information sources are rated at only a few bits/second, while a transmission system, for example, has a capacity many times that rate, then clearly the system is capable of processing several sources simultaneously. The manner in which this is organised has an important effect on the overall performance of a network of digital data transmission systems. The combining of information streams to make a single composite stream is termed multiplexing which, in digital applications, is known as time division multiplexing (TDM) because time is shared between the information transmitted from different sources.

At a digital receiver, a single stream of digits is recovered and may be required to be separated into its component streams. The receiver must have information to enable it to locate and identify those bits which constitute the components of the different information streams. During multiplexing, extra 'non-information' bits are added to the composite stream to enable this to be done. This process of marking the bits is known as 'framing' and is applicable not only during mutiplexing but also when identification of important bits is required as a time reference by the receiver. The process is illustrated in Fig. 2.

In an organised network, all the transmitter clocks are nominally identical and the receivers, by
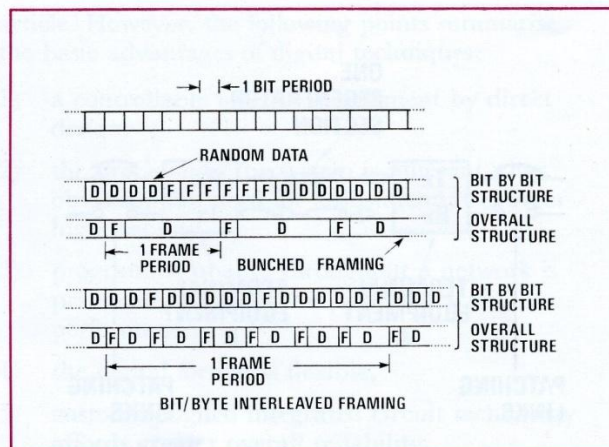

Fig. 2. This diagram illustrates the structure of a digit stream, with particular reference to the timing arrangements for identifying the important component parts of the stream. One means of providing a timing reference, known as 'framing', is to insert digits into the data stream so that they may be uniquely recognised at the receiving equipment. This can be done by inserting these framing digits altogether ('bunched' framing) or a few at a time spread evenly throughout the data frame period (bit, or byte, interleaved framing).

recovering their clocks from the incoming information, operate on the clock of a remote transmitter. This arrangement, see Figs. 3(a) and (b), can lead to practical problems which can be solved in one of two ways. Either the network is arranged to be locked in frequency to one oscillator, or the individual oscillators may be constrained to have nominally the same frequency and allowed to deviate only between certain well-defined limits. These two approaches lead either to a synchronous or to an asynchronous network respectively. The major constraint of the latter strategy is the conflict that arises when transmit and receive clocks are not identical. This can be overcome by adopting a multiplex framing scheme which includes disposable bits used as 'ballast' so that, when the received clock and parent station clocks are of different frequency, this 'ballast' can be used for making small adjustments to the incoming bit rate by adding or dropping bits in the multiplex structure. This process is shown in Fig. 4 and is known as 'pulse justification' or 'pulse stuffing'.

Transmission Media

The most common medium in the UK is coaxial cable, followed by microwave radio relays. Some new media are also becoming available, notably
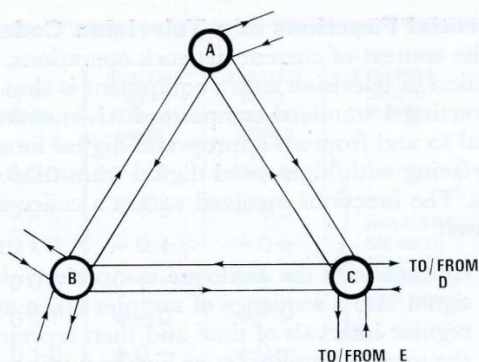
Fig. (3a). Part of a network of interconnected equipments which are exchanging digitally encoded information. The equipment at C, for example, exchanges information with similar equipment at nodes, A, B, D and E. The timing of all outgoing digit streams is controlled by the master timing control equipment of C, whereas each of the incoming digit streams is controlled by the master timing control at each source, e.g. A, B, D or E. In order to handle incoming data, therefore, the equipment at C (or any other network node) must be able to bring the incoming digit streams under the control of its own master timing control. Fig. 3(b) shows schematically how this may be achieved.

optical fibres. If digital transmission in these media is to be implemented speedily and economically, then applications to existing plant offer the best potential and network planning in the UK is progressing according to this policy.

However, where digital transmission is being directed to other applications such as broadcasting it might be economically and technically feasible to employ a new medium such as optical fibres. Typical applications could be signal distribution within studios or transmitters, or tie-lines to transmitters.

Signal Coding for Typical Links
Although the binary format for digital information processing is most convenient in general, it is not always so for transmission. The technical and economic factors governing system design may demand signal transformation into a format which is optimum for a particular transmission medium.
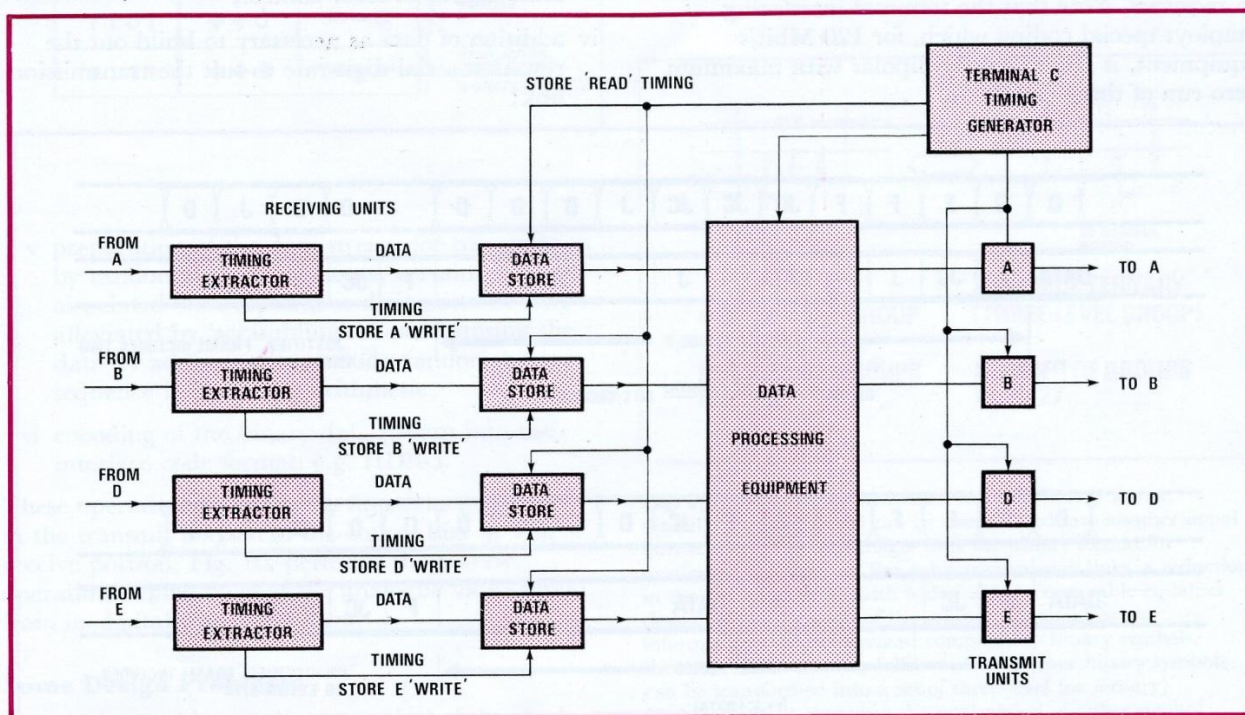

Fig. 3(b). This figure shows how the digit streams arriving at a nodal terminal equipment (C) are brought under the control of the master timing control. First, the incoming digit streams are individually entered into data stores, using timing derived from the digit streams themselves. Each stream is associated with a unique store. The digits are removed from the store under control of the parent master timing control at C. The stores will tend to fill up or empty depending on whether the incoming digit rates are greater or less than the parent station output digit rates. To accommodate these differences, additional digits are included in the digit stream and these can be used to control digit rate. This is further illustrated in Fig. 4.

For cable systems a 'binary to multi-level' code conversion is usually employed which reduces the repetition rate of the pulses transmitted. There are two codes which have been used for 120 Mbit/s equipment. They are very similar and are known as 4B3T and MS43. Each code takes groups of four binary digits and converts them into groups of three ternary symbols. The ternary symbols are represented by positive, zero or negative voltages applied to the cable so that, for example, the binary group 0101 could be represented by $0+0$ or $0-0$ groups depending upon the prevailing code mode status. This is illustrated in Figs. 5(a) and (b).

For microwave radio-relay schemes, four-phase phase-shift keying (PSK) of the carrier offers clear advantages over other modulation schemes. This modulation can be considered as a 'binary to four-level' code conversion where each phase can be defined specifically by pairs of binary digits, see Figs. 6(a) and (b).

Figures 7 and 8 show the typical transmitter terminal arrangements respectively for these two media; the complementary processors will be found in receivers. Note that the terminal interfacing employs special coding which, for 120 Mbit/s equipment, is High Density Bipolar with maximum zero run of three (HDB–3).

Essential Functions of a Television Codec

In the context of current network operations, the function of television codec equipment is that of converting a standard composite PAL-encoded video signal to and from an appropriate digital form for interfacing with high-speed digital transmission links. The functions involved within a codec are as follows:

i   conversion of the analogue composite video signal into a sequence of samples taken at regular intervals of time and then representing the sample amplitudes as binary numbers by means of a suitable analogue-to-digital converter (ADC);

ii   derivation of timing or clock signals from the sub-carrier burst such that the sample rate is exactly three times sub-carrier frequency, and that the serial clock is related to this rate;

iii   conversion of the eight-bit, parallel, binary representation of the sample amplitudes into serial form while adding further bits to enable some degree of error control;

iv   addition of data as necessary to build out the resultant serial digit rate to suit the transmission link;

$$\text{BIT RATE} = \frac{(F + JC + 2J + DATA)}{P} \text{ BITS/SECOND}$$

"JUSTIFIED" FRAME INCLUDES TWO EXTRA J BITS

$$\text{BIT RATE} = \frac{(F + JC + DATA)}{P} \text{ BITS/SECOND}$$
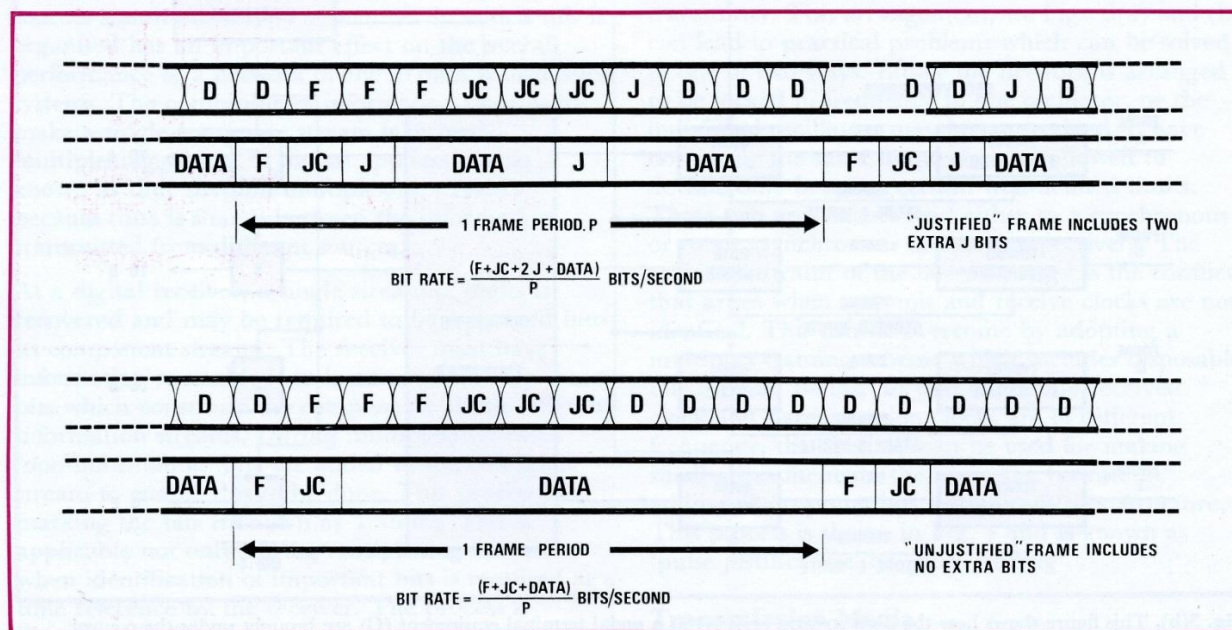
"UNJUSTIFIED" FRAME INCLUDES NO EXTRA BITS

Fig. 4. The process of digit rate control by means of added digits in the frame structure. This so-called 'pulse justification' employs these extra digits as 'ballast' so that they can be added or omitted when the stores in the terminal receiving equipment are filling or emptying excessively, see Fig. 3(b).

BINARY WORDS	POSITIVE MODE TERNARY WORDS	NEGATIVE MODE TERNARY WORDS	* EXAMPLE QUOTED IN TEXT
0000	0 − +	0 − +	INHERENTLY BALANCED CODE WORDS, COMMON TO BOTH MODES
0001	− + 0	− + 0	
0010	− 0 +	− 0 +	
1000	0 + −	0 + −	
1001	+ − 0	+ − 0	
1010	+ 0 −	+ 0 −	
0011	+ − +	− + −	CODE WORDS HAVE IMBALANCE IN SYMBOLS OF 1 UNIT. NOTE EXACT POLARITY BALANCE BETWEEN MODES
0101	0 + 0	0 − 0	
0110	0 0 +	0 0 −	
0111	− + +	+ − −	
1011	+ 0 0	− 0 0	
1110	+ + −	− − +	
0100	0 + +	0 − −	CODE WORD IMBALANCE 2 UNITS
1100	+ 0 +	− 0 −	
1101	+ + 0	− − 0	
1111	+ + +	− − −	CODE WORD IMBALANCE 3 UNITS

(*→ marks the 0101 row)

Fig. 5(b). A possible code transformation table for the ternary code 4B3T. The feature to note is the manner in which the ternary symbol sets are disposed according to their inherent polarity to provide an overall polarity balance when sequences of the sets are cascaded together to represent data streams. This is a more efficient use of the 11 excess ternary combinations than merely to discard them. [There are 16 ($=2^4$) combinations of four binary symbols whereas there are 27 ($=3^3$) combinations of three ternary symbols.] Note the absence of the 000 ternary symbol from the symbol set. A perpetuation of this symbol set would lead to regenerator timing control problems.
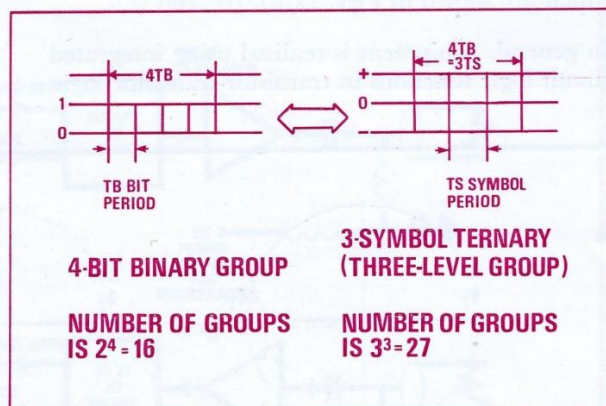
v preparation of the data stream for transmission by randomising the contents; certain problems associated with repetitive digit patterns may be alleviated by 'scrambling' or randomising the data by adding to it a pseudo-random binary sequence in modulo 2 arithmetic;

vi encoding of the binary data stream into the interface code format, e.g. HDB-3.

These operations describe the functions performed in the transmit portion of the codec, Fig. 9. The receive portion, Fig. 10, performs the reverse operations which recover the analogue video signal from its digitally encoded form.

Some Design Problems

One major problem is the generation of the clock frequencies required to operate the timing of the data processing within the codec. The problem is solved by extensive use of simple counters in conjunction with phase-locked loops. For example,

4-BIT BINARY GROUP

NUMBER OF GROUPS IS $2^4 = 16$

3-SYMBOL TERNARY (THREE-LEVEL GROUP)

NUMBER OF GROUPS IS $3^3 = 27$

Fig. 5(a). By means of code conversion, a binary format digitally encoded signal can be transformed into another signal format which has advantages over the binary format for particular applications. For cable transmission links, a reduction in the occupied bandwidth is desirable to ease cable equaliser design. If the duration of the symbols representing the information can be increased compared to binary symbols, then this requirement is fulfilled. A set of four binary symbols can be transformed into a set of three-level (or ternary) symbols without changing the total period of either symbol sets. Thus, the period of four binary symbols is equal to that of three ternary symbols, and so the duration of the ternary symbol is $33\frac{1}{3}\%$ longer than the binary symbol. This means that the ternary symbol repetition rate, known as the 'Baud rate', is three-quarters that of the binary symbol (digit) rate.

the final serial data clock can be synthesised to well within tolerance from the sub-carrier frequency by means of the arrangement illustrated in Fig. 11(a).

This solution also partly solves a second major problem which is that of building out the encoded video digit stream to a value appropriate to transmission, in this case 120 Mbit/s. By virtue of the clock generation process illustrated in Fig. 11(b), this building out is a synchronous operation which adds two extra, non-information, words during every 819 information words, so that 821 words exist in every repeating data block. This technique avoids the more complex problem of applying pulse justification techniques to this situation. By choosing the insertion of words rather than bits, use can be made of these words for other purposes (e.g. in-service error monitoring) and they may be so chosen as to have properties which cannot be repeated by true video data words, thus rendering them easily detectable at the receiver.

Another problem is the choice of a suitable scrambling mechanism. This is solved by means of a pseudo-random binary sequence, arrangements for which are shown in Figs. 12(a), (b) and (c).

In general, equipment is realised using integrated circuit logic functions in transistor-transistor logic

(TTL) and emitter coupled logic (ECL) which are used for the low-speed and high-speed processing respectively. As much processing as possible is performed at low-speed in the parallel mode to avoid the technical and economic penalties of high-speed serial processing throughout.

An IBA designed 120 Mbit/s codec is shown in the photograph of Fig. 13.

Conclusion

This article reviews the general field of digital transmission indicating the current trends and techniques. Of necessity it is brief, but an attempt has been made to cover the wide range of aspects which the subject presents.

Much has been reported in the technical literature on the theory and practice of digital transmission throughout the many years of its development. Thus, it is not a new idea, but it has high potential for exploitation, only a small part of which has as yet been realised. Great promise exists for an exciting future in this field.

Reference
1. Bennett, W R and Davey, J R 'Data Transmission', *McGraw-Hill*, 1965.
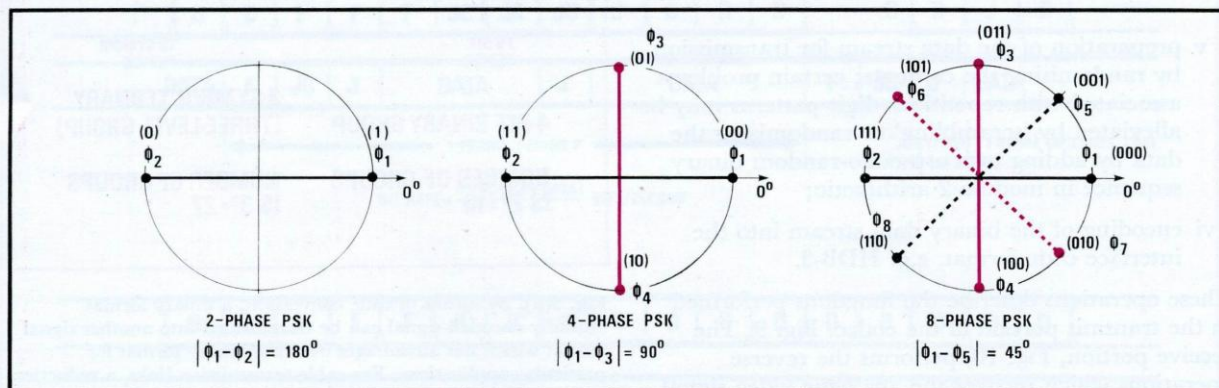

Fig. 6(a). Carrier phasor diagrams illustrating the process of phase modulation of a carrier by digital signals. If a single binary stream is required to be transmitted, then the binary 'O' and '1' could be coded as carrier phase 0° or 180° respectively. This scheme gives rise to an excessive bandwidth requirement.
If the single binary stream is divided into two streams, each one having a digit rate which is half that of the original stream and each stream is used to modulate one of two carriers in quadrature, then the occupied bandwidth is halved without significant penalty. The resultant scheme is effectively a carrier taking up one of four possible phases. The occupied bandwidth can be reduced further using eight carrier phases, but this scheme has certain disadvantages which make it less desirable than that using four phases, despite the reduction in occupied bandwidth. Note that for n-phase PSK, pairs of phases differ by $(360/n)°$ and that for 4-phase PSK, pairs of binary digits are required to specify each phase uniquely.

A	B	RELATIVE OUTPUT PHASE
0	0	0^0
0	1	90^0
1	1	180^0
1	0	270^0

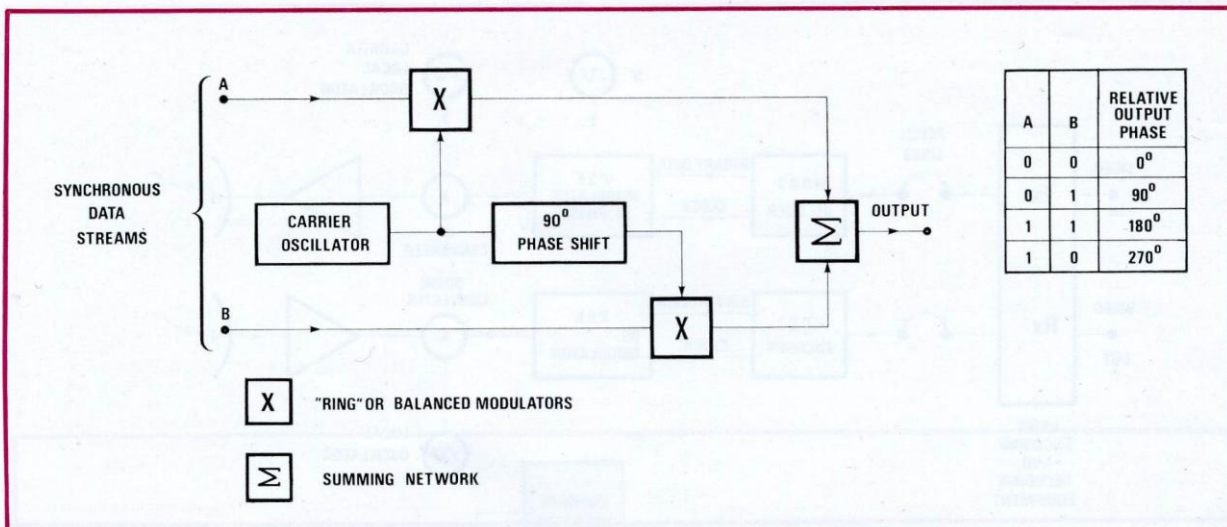X   "RING" OR BALANCED MODULATORS

Σ   SUMMING NETWORK

Fig. 6(b). A block diagram showing how a four-phase modulator may be realised using balanced modulators. This phase shift keying method is common when the modulated frequency is in the vhf band. The intermediate frequency (i.f.) is usually translated to a higher frequency in the shf band for use as a carrier in microwave radio relay equipment. Modulators employing an i.f. in the uhf band are uncommon due to realisation problems, but direct modulation techniques employing delay lines can be used at frequencies in excess of 1 GHz.
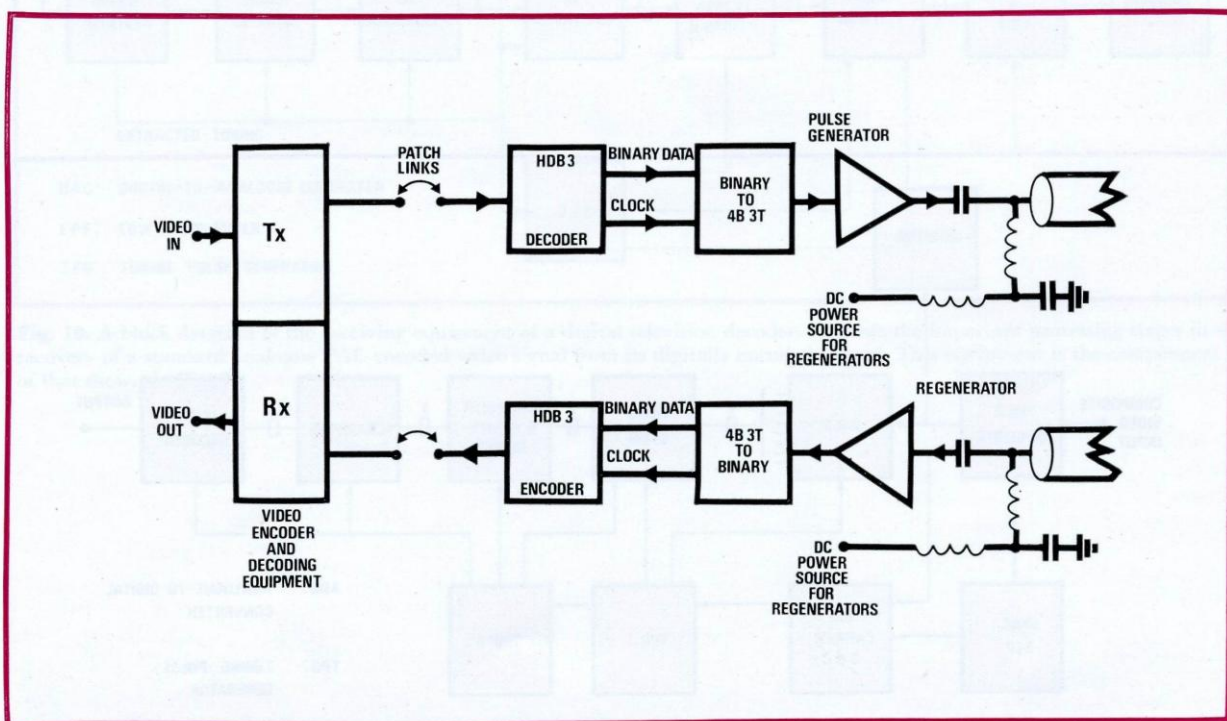

Fig. 7. A schematic representation of the transmitter and receiver equipment required at the terminals of a digital cable link. The encoding of the analogue video signal into digital form (for this example) does not take place in the link terminals, but is performed in separate equipment, and the signal is conveyed to the link terminal proper by means of 'patching' links. There is usually a special digital coding format for this interface. The link terminal equipment must therefore operate between the interface code and the code used for the cable system itself (e.g. 4B3T). This is usually done using binary format as an intermediate stage.
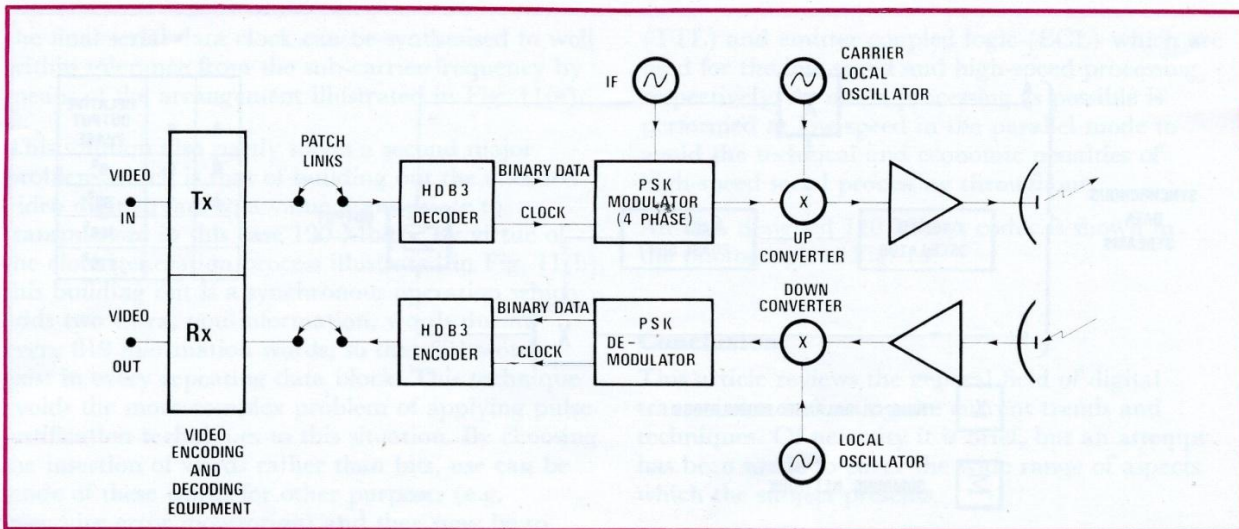
Fig. 8. A schematic representation of a digital radio relay system. The encoding of any analogue signals into digital form does not take place in the radio system terminal equipment but elsewhere, and patching links are employed to connect the equipments. This interface usually employs a special digital code format. The link terminal equipment converts between this code format and the PSK modulated carrier, using the binary format as an intermediate stage. The diagram shows the arrangement of the PSK modulator and demodulator as well as the frequency translation equipment.
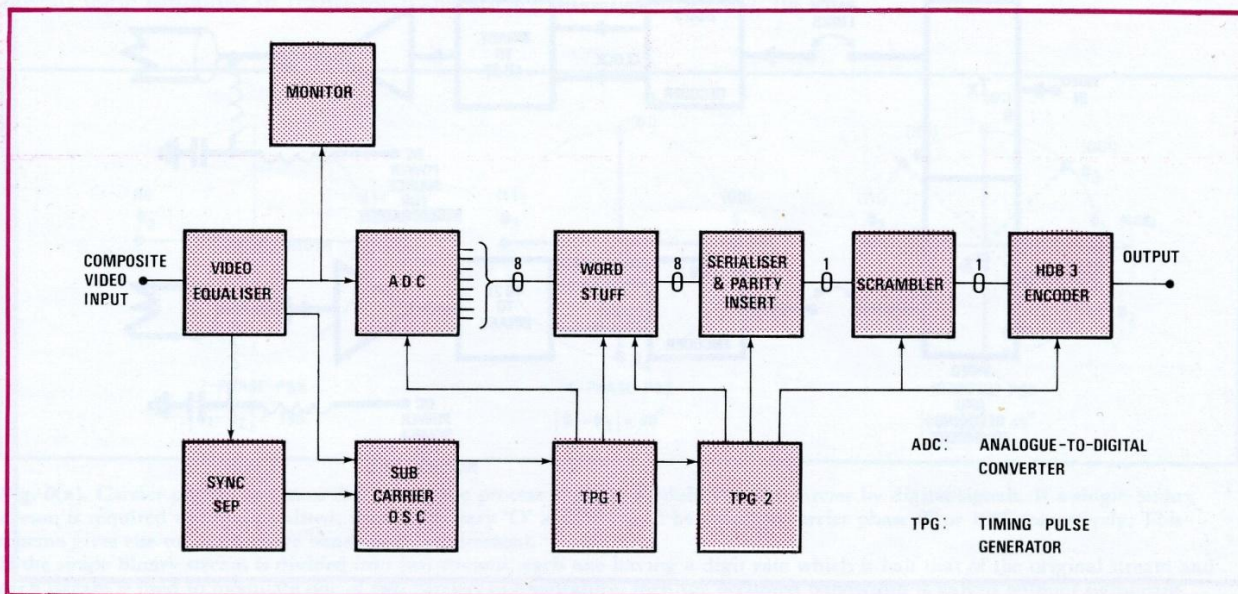

Fig. 9. A block diagram of the transmitting equipment of a digital television encoder. It shows the important stages of processing involved in converting a standard PAL encoded analogue video signal into digital format. The diagram is largely self-explanatory; a description of the functions is given in the text. The complementary receiving equipment is illustrated in Fig. 10.
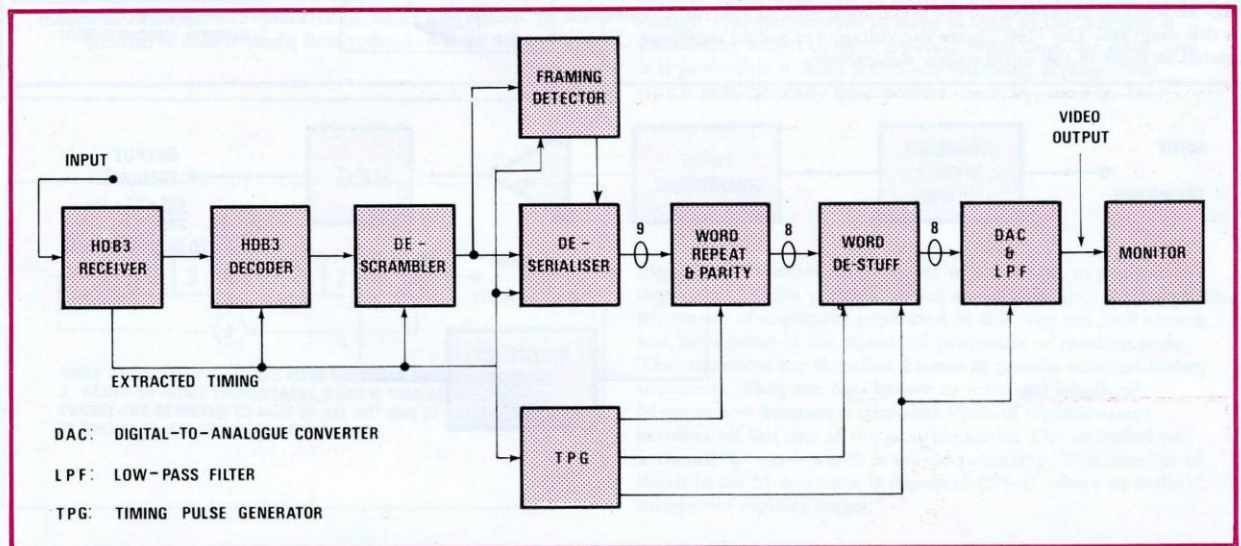
Fig. 10. A block diagram of the receiving equipment of a digital television decoder. It shows the important processing stages in the recovery of a standard analogue PAL encoded video signal from its digitally encoded format. This equipment is the complement of that shown in Fig. 9.
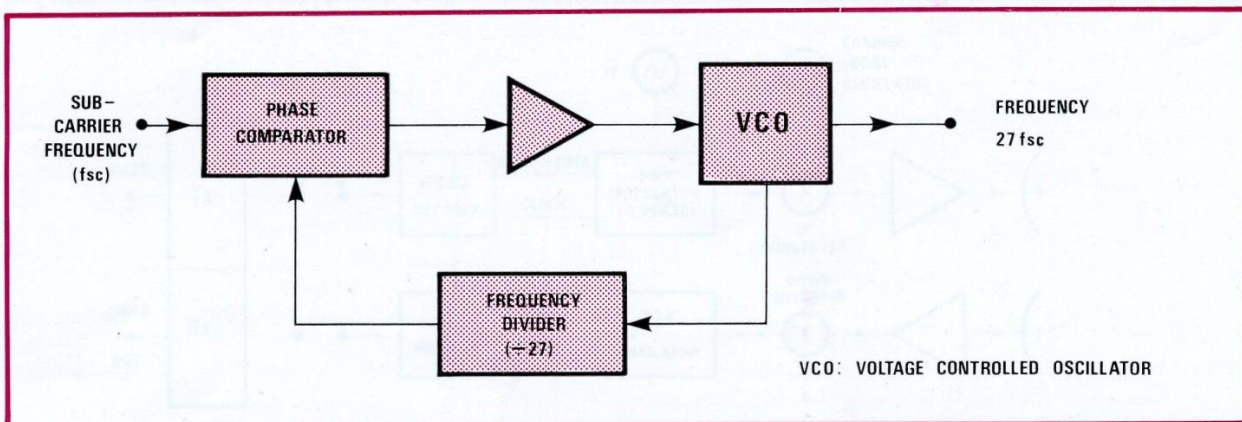
Fig. 11(a). The generation of the serial digit timing control is performed by means of a phase-locked loop arrangement as shown in this diagram. The loop causes the voltage controlled oscillator (VCO) to take up a frequency and phase which is directly related to those of the input colour sub-carrier.
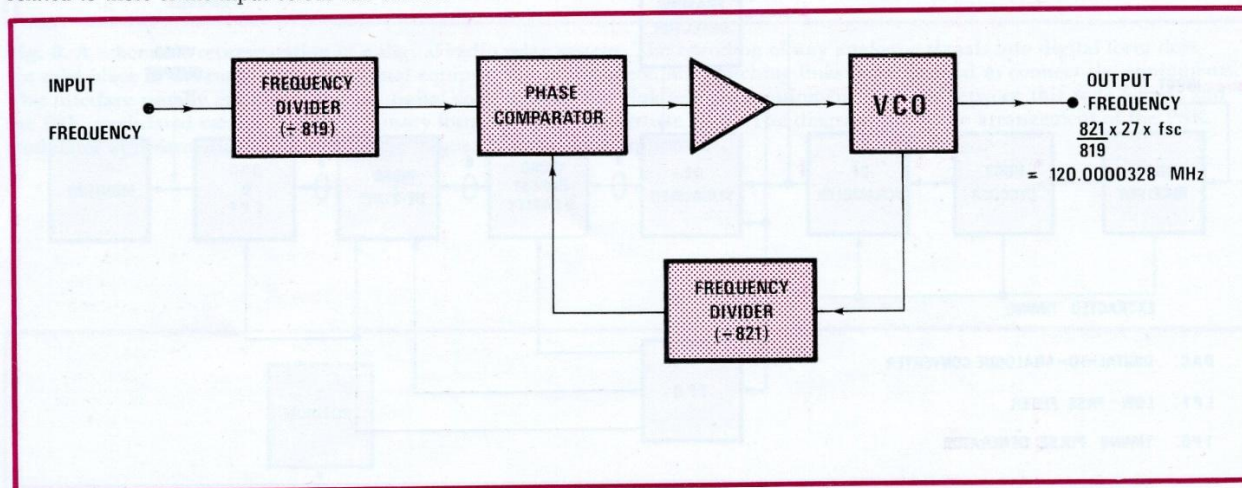
Fig. 11(b). A method of generating a serial digit timing control signal at 120 MHz which is locked in phase and frequency to the colour sub-carrier. This phase-locked loop arrangement produces a very accurate final digit rate which is well within Post Office tolerance of $\pm$ 15 ppm. By locking the serial timing to the sub-carrier frequency, the bit rate build out process is simplified and avoids the use of pulse justification techniques.

Fig. 13. The IBA designed 120 M bit/s coder/decoder pair. Each occupies a complete 19" shelf and includes most of its own power supply requirements.

THE OPERATION ILLUSTRATED BY ⊕ IS MODULO-2 ADDITION, DEFINED BY TABLE 1. NOTE THAT TWO OF THESE OPERATIONS IN SERIES PRODUCES THE ORIGINAL INPUT DATA. ALSO NOTE THAT ⊕ AT RECEIVER MUST HAVE THE CORRECT PHASE OF SCRAMBLING SEQUENCE IN ORDER TO DE-SCRAMBLE CORRECTLY.

TABLE 1

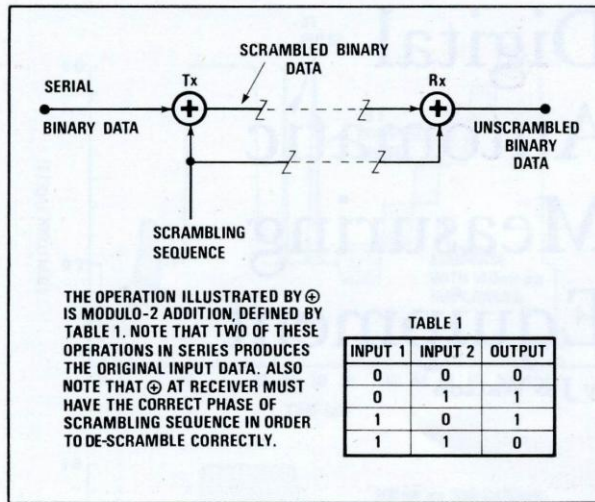| INPUT 1	INPUT 2	OUTPUT
0	0	0
0	1	1
1	0	1
1	1	0
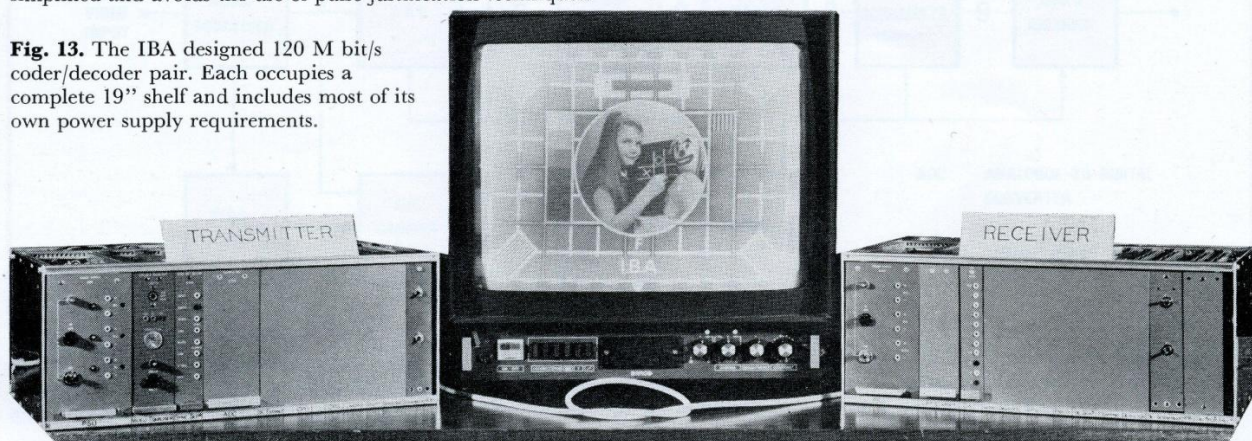
Fig. 12(a). The basic idea in scrambling a digit stream is to prevent the occurrence of long repeated patterns which can lead to regenerator design problems. Ideally, the scrambling mechanism is the combination of the digit stream with a known digital pattern using modulo 2 arithmetic.

The mechanism does not increase the digit rate. At the receiving equipment, however, an identical digital pattern must be made available to recover correctly the required digit stream. It is undesirable to have to send to the receiver a scrambling sequence by a separate route from the data, and it is preferable to have a self-synchronising arrangement which automatically descrambles correctly, see Fig. 12(c).
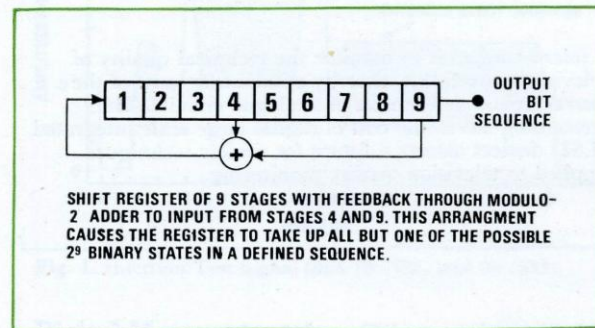

SHIFT REGISTER OF 9 STAGES WITH FEEDBACK THROUGH MODULO-2 ADDER TO INPUT FROM STAGES 4 AND 9. THIS ARRANGMENT CAUSES THE REGISTER TO TAKE UP ALL BUT ONE OF THE POSSIBLE 2^9 BINARY STATES IN A DEFINED SEQUENCE.

Fig. 12(b). A serial shift register may be used to generate a sequence of digits which is useful as a scrambling sequence. The properties of sequences generated in this way are well known and have some of the statistical properties of random noise. The sequences are therefore known as pseudo random binary sequences. They are also known as maximal length or M-sequences because a complete cycle of register states involves all but one of the possible states. The excluded one is the all 'O' state which is self-perpetuating. The number of digits in an M-sequence is therefore (2^m-1) where m is the number of register stages.
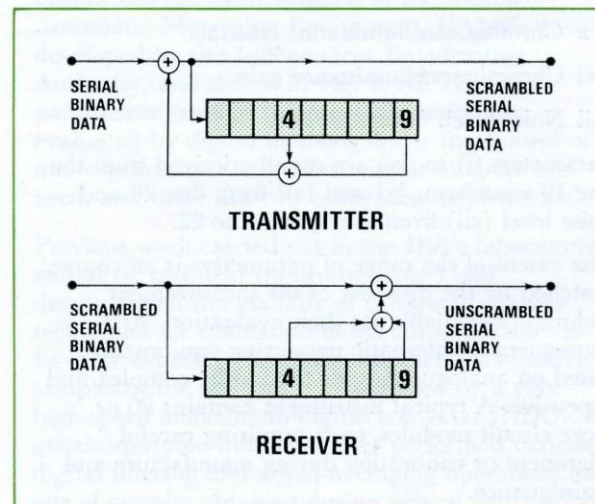
Fig. 12(c). The arrangement of a self-synchronising scrambler. This facility is provided since the relative delay between digits in the sequence is fixed by the scrambler register feedback connections, so that if these connections are also used at the de-scrambler the relative delays remain unchanged by the absolute delay in the transmission path. The unfortunate disadvantage of this arrangement is that every digit error gains access to the output by three different routes: directly, via the fourth register stage and via the ninth register stage. This means that the number of transmission errors is multiplied by three at the output of the descrambler, and this so called error extension can create problems in error control.

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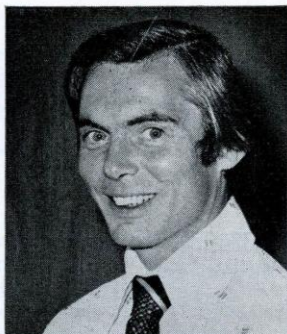
Digital Automatic Measuring Equipment

by J B Watson

Synopsis

Several proprietary automatic measuring equipments for insertion test signal distortion analysis are now available to the broadcaster. All employ analogue circuit techniques for their critical measurement functions, and are therefore expensive to manufacture and maintain. The IBA's Digital Automatic Measuring Equipment (DAME) uses a micro-computer to monitor the technical quality of television waveforms, thereby eliminating most of the characteristic deficiencies of analogue circuits. The continuing fall in the cost of digital large scale integrated (LSI) devices assures a future for similar techniques applied to television quality monitoring.

Introduction

Measurements based on insertion test signals (ITS) play a significant part in monitoring the technical quality of a modern television transmission chain. Figure 1 shows the ITS waveforms carried on lines 19 and 20 (also on lines 332, 333) of the television waveform used in the United Kingdom, and either automatic or manual methods can be used for extracting the values of a number of standard technical parameters from these test signals. Twelve of the parameters most frequently used are as follows:

   i Sync pulse amplitude

   ii Low frequency bar amplitude

   iii Low frequency bar tilt

   iv 2T pulse shape (K-factor)

   v 2T pulse amplitude (pulse/bar ratio)

   vi Luminance non-linearity

   vii Chrominance differential phase

  viii Chrominance differential gain

   ix Chrominance/luminance delay

   x Chrominance/luminance crosstalk

   xi Chrominance/luminance gain

  xii Noise level.

Parameters (i) to (ix) are usually derived from the line 19 waveform, (x) and (xi) from line 20 and noise level (xii) from the 'quiet' line 22.

The extent of the range of parameters is, of course, matched by the diversity of the measurement techniques available for their evaluation. As a consequence, automatic measuring equipments based on analogue circuits tend to be complex and expensive. A typical instrument contains 20 or more circuit modules, each requiring careful alignment or calibration during manufacture and maintenance.

Fig. 1. Insertion Test Signal lines 19 (332) and 20 (333).

Fig. 2. Digital Automatic Measuring Equipment.
The decade switches near the centre of the equipment select the parameter to be presented on the $3\frac{1}{2}$-digit LED display immediately above. Alternatively, the stored parameter limit values held in the read-only memories can be displayed.

When operating in the 'auto' mode the equipment sequentially monitors a maximum of seven video sources and compares the measured parameter values with the stored limits. The two banks of LEDs situated to the left of the digital display indicate which, if any, of the parameters exceed the limiting values (three pairs of limits, associated with different video sources, are stored).

Digital Measurements

A new approach to the measurement of ITS parameters has been adopted in the Digital Automatic Measuring Equipment[1], DAME, developed by the Independent Broadcasting Authority, and shown in Fig. 2. All 12 of the parameters listed in the previous section are evaluated by digital methods under the control of a micro-processor. Only seven circuit modules are used, and there are two calibration adjustments.

Previous work carried out in the IBA's laboratories and at its Lichfield transmitter site[2,3] had demonstrated the viability of computer analysis techniques for evaluation of television parameters. In these experiments a large number of successive samples of the test line were digitised by a very high-speed analogue-to-digital converter (ADC). A general-purpose mini-computer performed various digital filtering and signal-averaging operations on sets of samples obtained during several field periods,
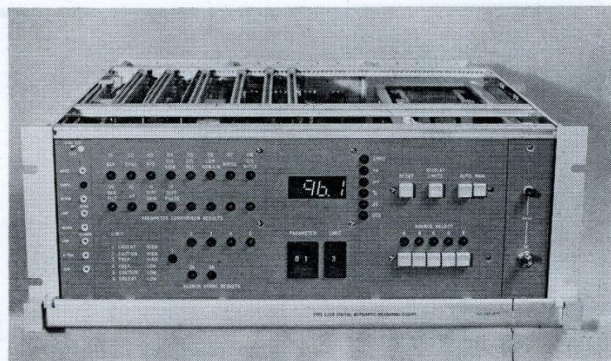
finally calculating the values of the parameters and displaying them on a teletype printer.

DAME uses many of the software procedures developed for this earlier system but substitutes a 4-bit micro-computer for the 16-bit mini-computer, and a standard process control type of ADC for the high-speed converter. The latter substitution is made possible by taking a small number of samples of the test line waveform in each field, ensuring that the time interval between successive samples always exceeds the ADC conversion time. These changes in design philosophy resulted in a digital measuring system sufficiently inexpensive for on-site transmitter monitoring and supervisory control rather than, as with the Lichfield system, central off-air monitoring. The operational advantage of on-site monitoring is that local automatic corrective action can be taken directly in the event of a fault, whereas a central monitoring station depends on a remote control link for a similar action.

System Hardware

The DAME block schematic is shown in Fig. 3. All slow-speed data transfer operations such as remote-control/telemetry functions, control switch inputs, and display lamp outputs are handled directly by the micro-computer via its input/output
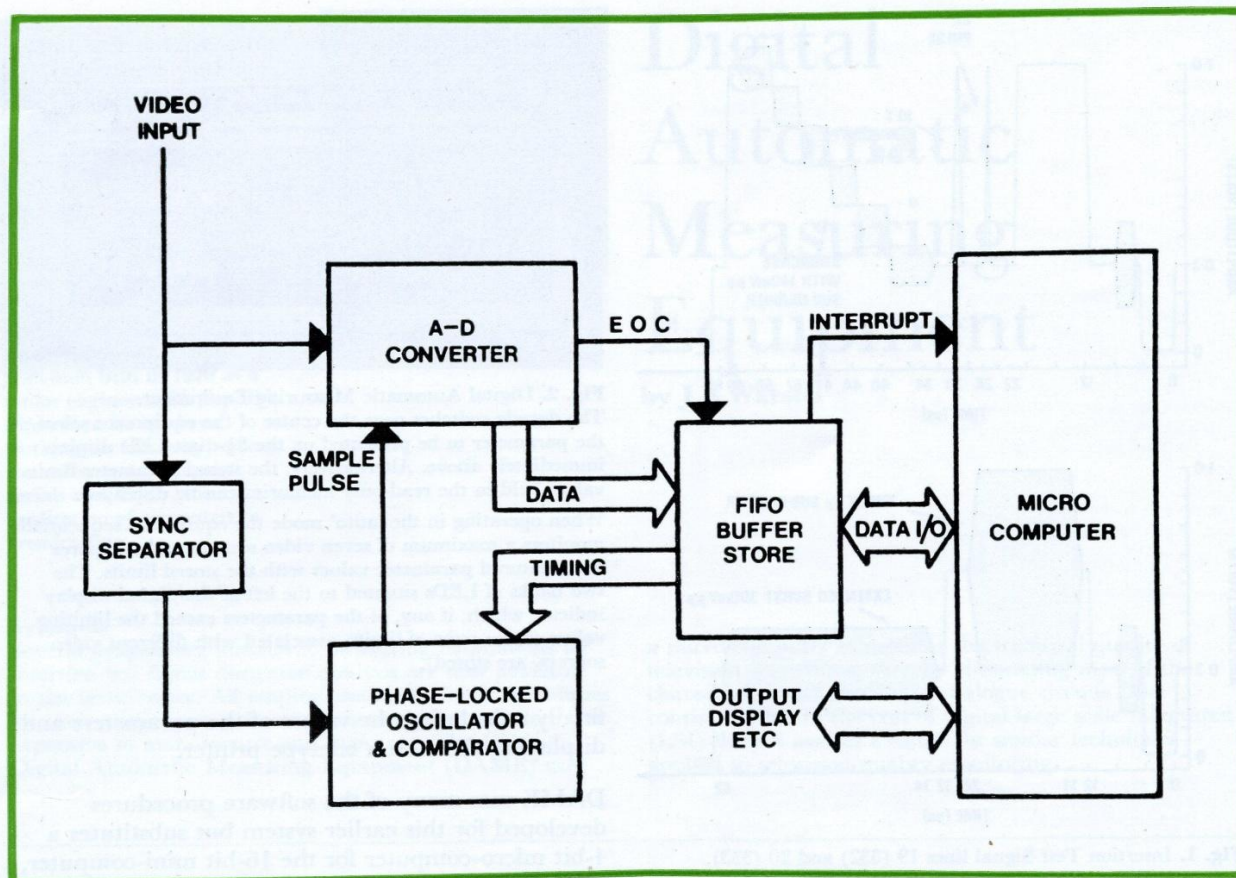
Fig. 3. Schematic diagram of a Digital Automatic Measuring Equipment (DAME).
At the beginning of the sample-gathering sequence, four sample timing values are stored in the first-in-first-out buffer. These timing numbers are compared in sequence with the divider chain of the phase-locked oscillator, giving rise to four sample pulses which trigger the analogue-to-digital converter. On receipt of an 'end of conversion' pulse (EOC) the FIFO discards the current sample timing data and accepts a 10-bit video sample from the ADC. After four such operations the FIFO contains four digital samples corresponding to the designated sample positions. An interrupt signal is then generated, causing the computer to read in the sample values and produce four new timing numbers. The interrupt handling routine also services all the slow-speed data ports, i.e. front panel switches, display outputs and remote control/telemetry highways.

structure. High-speed video sample data, however, is buffered by a four-word first-in-first-out memory, FIFO, which performs two functions. Sample timing data (12 bits) enters from the computer and is presented to the digital comparator input of the oscillator/comparator circuit. Each timing value gives rise to a sampling pulse before it is discarded and replaced at the 'top' of the FIFO by a 10-bit value from the ADC. Four such operations take place in each alternate field period, then the micro-computer interrupt line is energised. The task of the interrupt handling software is to read-in the

four sample values now contained in the FIFO and to provide four new timing codes for use in the next frame period. This arrangement isolates the relatively slow (10.8 µs cycle time) proprietary 4-bit micro-computer from the higher speed data acquisition process, and permits a more efficient block data transfer into its memory. The choice of four samples per frame was dictated by the target of 15 seconds or so for the instrument to scan the total number of samples necessary for the sample calculations. This last point has been previously discussed by Schaffer[4].

In the oscillator/comparator module a selection of the sampling time, in increments of 74.1 ns, is achieved by comparing a 12-bit sample timing code with the divider chain of the phase-locked loop. The two most significant bits of the 12-bit code are reserved for selection of lines 19 to 22 inclusive.

The ADC shown on the block schematic is a proprietary hybrid module converting video samples to 10-bit digital numbers in less than 4 μs. It is preceded by a sample-and-hold circuit based on a matched quad of Schottky diodes. The designed aperture uncertainty time is better than 200 ps.

The micro-computer program is contained in static MOS read-only memories of 2048-bit capacity. The devices are fitted with quartz lids through which short-wave ultra-violet light can be directed for erasing the stored bit pattern, re-programming is then possible. Figure 4 shows one of the two computer cards used in the equipment. The eight chips near the lower edge of the board provide for 2048×8-bit words of program storage. The 24-lead processor chip is centrally situated on the left-hand side, with four read/write memories for temporary data storage immediately above it. Also provided on this board are logic circuits for eight 4-wire input/output (I/O) ports. The second computer board acts merely to extend the memory and the number of I/O ports.

DAME Software

Some 4000 instruction words are used in the DAME operating program, approximately half of these being concerned with the parameter calculations. The remainder are divided, more or less equally, between the real-time executive and the special arithmetic routines such as arctan, log, multiply and divide. Most of the arithmetic package is based on 16-bit fixed-point numbers, care being necessary to scale all values correctly for the best accuracy. Programs were written in the micro-computer assembly language and assembled on a larger machine equipped with a cross-assembler.

The processor used has a single-level interrupt capability, which is used mainly in the data acquisition cycle. In addition, the television frame-rate interrupt signals provide a basic system timing reference initiating a scan of all front panel switches, remote control input highways, etc. This ensures
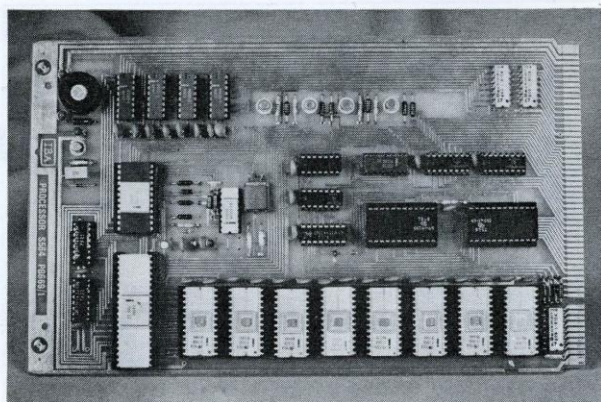

Fig. 4. DAME Micro-Computer Card.
The 24-lead processor chip—an Intel 4040—is on the centre left. This device can decode 60 different instructions and has a single-level interrupt facility. Immediately above it are four read/write memory circuits (for variable data) containing 320×4-bit data locations. Program memory is organised in an 8-bit format, and is held in the eight 4702A PROMS on the lower edge of the card. The DAME operating program can be changed after irradiating the PROMS through their quartz windows with short-wave ultra-violet light.

Also included on this card are eight 4-line output ports and four 4-wire input ports—the computer's means of communication with the external environment. A second computer card extends the program capacity to 4096 words and the data storage to 1280 bytes.

that status changes in these external functions are recognised within 40 ms.

Colour Measurements

As an example of the algorithms used in calculating colour parameters, differential gain, differential phase and luminance non-linearity will be considered. All three measurements are derived from the staircase waveform on line 19, a section of one of the staircase steps being shown in Fig. 5. A characteristic of the PAL colour sub-carrier waveform on the test lines is that it follows an eight-field phase sequence. If alternate fields are disregarded the four possible sub-carrier phases differ from each other by exact multiples of 90°. In Fig. 5 the nth sampling position is fixed in relation to the test line for each of the four alternate fields, and the samples A, B, C and D are taken. The following relationships then apply:

Luminance value, $V_L = \frac{1}{4}(V_A + V_B + V_C + V_D)$ (1)
In-phase colour component,
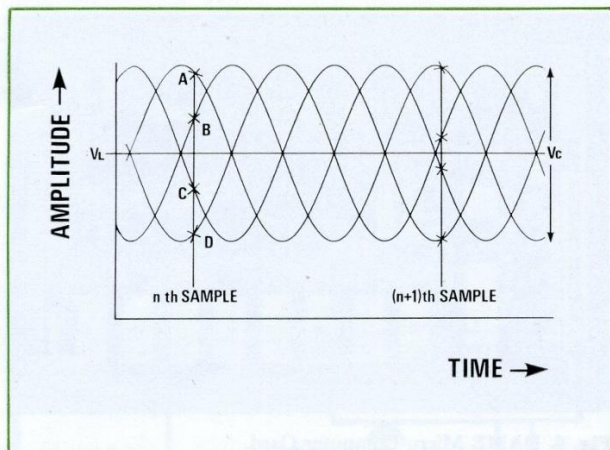$$V_C \sin \phi = V_A - V_D \quad\text{———(2)}$$

Fig. 5. Sampling process on staircase waveform.
The eight-phase PAL sequence characteristic enables the evaluation of differential phase and gain to be simplified by presenting sine and cosine colour sub-carrier components at television frame intervals. After eight field periods DAME will have acquired samples, A, B, C and D. These samples contain sufficient information to calculate the phase and amplitude of the chrominance waveform. In practice, eight sets of samples are averaged before the differential phase and gain calculations are performed. By adjusting the timing between each sample set to a few degrees less than a whole cycle of the colour waveform, the effect of a 'dither' signal is achieved where the resolution of the analogue-to-digital converter is enhanced beyond its 10-bit capability.

Quadrature-phase component,
$$V_C \cos \phi = V_C - V_B \qquad (3)$$

From (2) and (3) may be deduced:

Chrominance amplitude,
$$V_C = \sqrt{(V_A - V_D)^2 + (V_C - V_B)^2} \qquad (4)$$

and
$$\phi = \arctan \left\{ \frac{V_A - V_D}{V_C - V_B} \right\} \qquad (5)$$

where the colour sub-carrier phase, ϕ, is referenced to some arbitrary constant.

In practice, a certain amount of signal averaging takes place before equations (1), (4) and (5) are used by the micro-computer. The nth and (n+1)th sample positions shown in Fig. 5 are separated by a few degrees less than a complete cycle of sub-carrier. This is brought about by a suitable choice of oscillator frequency in the oscillator/comparator module of Fig. 3. The terms on the right hand side of equations (1) to (3) are averaged for eight sets of samples, resulting in a significant improvement in resolution over the 10-bits from the ADC. After averaging, the values V_L, V_C and ϕ are calculated on each step using equations (1), (4) and (5), following which the standard formulae for non-linearity, differential phase and differential gain are applied.

Similar techniques for separating chrominance and luminance components are employed in evaluating chrominance/luminance gain, delay and crosstalk. Here, however, the sub-carrier amplitude is an appreciable fraction of the instrument's dynamic range, so a simplified averaging process is acceptable.

Applications

DAME in its original conception was designed to meet the need for local transmitter site monitoring. Typical required accuracies are $\pm 2\%$ for most of the parameters, the one exception being bar height where $\pm 1\%$ is desirable. Chrominance/luminance delay, noise level and differential phase are monitored to within ± 5 ns, ± 2dB and $\pm 2°$ respectively. Logical decision software capable of detecting faults in the transmitting equipment or video inputs is included. This allows executive action, such as a change-over to stand-by equipment, to be taken when any parameter exceeds the pre-set limit value. Other future applications may include a low-cost noise measuring set, distortion correctors for television transmitters, and a highly accurate equipment for studio measurements. The large software content of DAME makes possible a wide variety of equipment types sharing a common hardware basis.

References

1. British Patent Application No. 47330/74.
2. McKenzie, G A and Vivian, R H 'Automatic Measurement of Television Waveforms', *IERE Conference Proc.*, 1970, **17**, 451—466.
3. Vivian, R H 'Software for television waveform measurements by computer', *IEE Conference Publication*, 1973, **103**, 43–49.
4. Schaffer, J 'Computer monitoring of TV Signals', *Wireless World*, January 1975, **81**, 37–42.

Glossary
of Terms
and
Abbreviations

A Glossary of Terms and Abbreviations used in Digital Television Data Processing and Transmission

ABSOLUTE ADDRESS

A binary number that is permanently assigned as the address of a storage location.

ACCESSING

Obtaining stored data in the form of words or bytes by means of a memory address. The term is also used to denote communication with a peripheral via an interface.

ACCUMULATOR

A register in which the result of an operation is formed.

ADDRESS

A label, name or number which designates a location where information is stored.

ALGORITHM

A prescribed set of well-defined rules or processes for the solution of a problem in a finite number of steps.

ALIASING COMPONENTS

Spectral components arising from the process of sampling which are not in the signal before sampling. These components may fall inside or outside the spectrum of the unsampled signal.

ALPHANUMERIC

Pertaining to a character set that contains both letters and numbers, and usually other characters as well.

ASCII

American Standard Code for Information Interchange. A 7-bit code representation of alphanumeric and control characters, substantially similar to that known as ISO7. A parity bit is frequently added to provide an 8-bit code or byte.

ASSEMBLE

To translate from a symbolic computer program to a binary program by substituting binary operation codes for symbolic operation codes and absolute or re-locatable addresses for symbolic addresses.

ASSEMBLY LANGUAGE

A computer language, generally specific to a particular CPU, whose elements usually consist of operation codes or mnemonics representing the *instruction set* of the CPU together with some 'pseudo instructions'. Such a language allows the use of symbolic names, for example for labels and data areas. When a program written in such a language is assembled the operation codes or mnemonics generate the appropriate instruction. The 'pseudo-instructions' usually do not generate code, but control the way in which the assembler works. The difference between an assembly language and a *high level language* is that of the complexity of syntax allowed and that statements in an assembly language are very much more closely related to the *instruction set* of the CPU. Assembly language statements are usually (not exclusively) in a one-one correspondence with the instruction set.

ASSEMBLY PROGRAM

A program which directs a computer to assemble a text written in an *assembly language*.

BAUD

A unit of signalling speed used in data transmissions. One Baud corresponds to a rate of one signal element per second.

BIT

An abbreviated form of the words 'binary digit'.

BOOTSTRAP	A technique or device designed to bring itself into a desired state by means of its own action, e.g. a routine the first instructions of which are sufficient to bring further instructions into the computer from an input device.
BRANCH	A point in a program where one of two or more choices is made under control of the program.
BUFFER	A storage area.
BYTE	A group or sequence of bits, the length of which represents the unit from which data words and instructions are built.
CCD	Charge Coupled Device. A MOS structure with the ability to transfer electrical charge from one element storage location to the next in response to applied 3- or 4-phase clock pulses. Storage devices with capacities of up to 16K bits are already commercially available and although currently expensive the costs are expected to fall rapidly in the near future making CCDs an economic alternative to magnetic discs and similar mass storage devices.
CHARACTER	A single letter, number or symbol used to represent information.
CLEAR	To erase storage locations by replacing the contents, normally with zero.
CMOS	Complementary Metal Oxide Semiconductor is MOS technology utilising both P-type and N-type silicon devices in each gate. The power consumption of CMOS is very low, making them suitable for such things as electronic watches.
CODING	To write instructions for a computer using symbols meaningful to the computer, or to an assembler, compiler, etc.
COMPILE	To translate or convert a text written in symbolic form in a *high level language* into *machine code* or *object code*. The symbolic text is checked for correct syntax for the language used and code is generated either directly by the compiler or in the form of calls to appropriate subroutines from a comprehensive library. (See LOADER.)
COMPLEMENT	The complement of a variable or function is the binary opposite or inversion of that variable or function.
CONTOUR DISTORTION	A subjective effect arising from quantising in a picture. A gradual change between areas of different colour or luminance is replaced by a series of abrupt changes.
CPU	Central Processor Unit. A hardware logic network, usually within a computer system, which, with reference to an address counter: 1. reads instructions from data storage or input devices, 2. effects such instructions, 3. controls the flow of data to storage devices or output devices.
CYCLE TIME	—of a computer: the time taken by the processor to obtain from the memory, and to decode, one instruction *word* or *byte*. Instructions which occupy more than one word (or byte) will take more than one cycle to complete. —of a program: pertaining to a continuously cycling program, the time taken to perform one major loop of the program. Since the program operation may depend on data or other external conditions, the cycle time will not be exactly constant.

DATA	A general term used to denote any facts, numbers, letters or symbols.
DE-BUG	To detect, locate and correct mistakes in a program.
DE-LIMITER	A character that separates and organises elements of a program, e.g. 'space', 'carriage return' characters. They are often used by an assembler or compiler to recognise the end of a particular symbol, or sequence of symbols.
DIFFERENTIAL CODING	Method of coding in which the information transmitted between the coder and decoder characterises the difference between the true value of a sample of the signal and a predicted value calculated from preceding transmitted samples.
DIGITAL FRAME	A set of consecutive digit time slots in which the position of each digit time slot can be identified by reference to a frame alignment signal. The frame alignment signal does not necessarily occur, in whole or in part, in each frame.
DIGITAL FRAMING STRUCTURE	Descriptions of the allocation of time slots in a digital frame between information digits (message) and service digits (alignment, justification, signalling, etc).
DISC	A device for storing (usually millions of bits of) data by magnetic means, which serves as a peripheral device for a computer. The thin disc, covered with a magnetic material, rotates at high speed and a moving arm transverses the disc in order to read or write data at a specific position. Reading or writing a disc is relatively slow compared with the internal memory of a computer and they are therefore used only as 'back-up' storage for infrequently-used information.
DITHER	The deliberate addition of a cyclic or randomly varying component to an analogue signal before coding, to reduce the subjective effects of quantising noise.
DMA	Direct Memory Access. This is a feature of a computer enabling a high-speed transfer of data between the internal memory and a peripheral device, without involving the processor.
DOUBLE PRECISION	Pertaining to the use of two computer words to represent one number, for example, to improve the precision of calculations.
DPCM	Differential Pulse-Code Modulation is PCM in which the information conveyed is represented by the numerical differences between values related to the samples of an original quantity.
DUMP	The process of copying all or part of the memory's contents, usually on to an external storage medium.
EDGE BUSYNESS	Effects of sampling and quantising showing as apparently random, fluctuating irregularities on the contours of a picture.
EDIT	The process of arranging information for output or input.
EPROM	Erasable PROM. A ROM which may be programmed and erased and re-programmed repeatedly by the *user*.

ERROR CONCEALMENT   Measures taken to reduce the subjective effect of digital errors when they cannot be actually corrected. The repetition of the last correct sample is an example of error concealment.

ERROR CORRECTION   Process of correcting errors affecting the information digits, by using appropriate transmission codes.

ERROR MITIGATION   Equivalent to 'error protection', which should be used instead of 'error mitigation'.

ERROR PROTECTION   Measures for protecting a system against the effects of digital errors. The measures may combine correction and concealment of the errors.

EYE   (Eye Pattern) An oscillograph of a data waveform in which the 'X' axis represents a time span of one bit period and the 'Y' axis represents the waveform amplitude.

EXECUTIVE ROUTINE   A routine that controls or monitors the execution of other routines.

FIRMWARE   Programs or instructions stored in read-only memories usually, but not exclusively, related to systems in which, 'executive' level programs are stored in read-only memory, while 'application' programs are stored in read/write memory, e.g. in core stores. The distinction is considerably less sharp in special-purpose micro-processor applications where all programs may be stored in read-only memory.

FLOWCHART   A graphical representation of the sequence of instructions required to carry out a data processing operation.

FOLDOVER DISTORTION   Distortion arising from aliasing components falling within the spectrum of the original signal.

FORMAT   The structure in which data is presented (e.g. a Table). Where a fixed format is employed, information of a particular kind or significance will always appear in the same designated area.

FUNCTION KEY   A key controlling a series of predetermined events collectively representing an identifiable and useful function (e.g. the 'multiply' and 'sine' keys of a pocket calculator).

GRANULAR DISTORTION (SOUND)   The subjective effect of quantising errors on low-level sound signals.

HARDWARE   The term given to physical (particularly data processing) equipment, e.g. mechanical, electrical or electronic devices.

HEX CODE   Hexa-decimal code. Code with base 16 in which, in the written form, equivalents of the two-digit decimal numbers 10–15 are replaced by (for example) the letters A–F. It is convenient to use Hex Code when computer words are easily separable into 4-bit bytes. ($2^4=16$).

HIGH LEVEL LANGUAGE   A language which provides for the concise statement of an algorithm, often biassed to a particular problem environment. A high level language therefore allows the programmer to devote relatively more time to the problem itself, rather than in keeping track of register usage and variable locations. 'ALGOL' and 'FORTRAN' are examples of such a language.

HYBRID PCM   Method of coding in which the information contained in the original signal is transmitted partly in digital form and partly in analogue form.

INSTRUCTION CYCLE TIME	The time required by CPU to execute an instruction.
INSTRUCTION SET	A collection of instructions specific to a particular CPU.
INTERFACE	A circuit which links a peripheral device to a computer to enable the transfer of data between the two. In a more general sense, an interface may be that means by which interconnection is made between any two systems or subsystems. 'To interface' means to connect together two systems or subsystems (usually a computer and a peripheral device) in such a way as to enable the transfer of data between the two.
INTER-FRAME CODING	Method of coding applicable to sequences of moving pictures, making use of the temporal correlation between successive pictures.
INTERRUPT	A special signal raised by any device which causes the normal flow of processor operations to be temporarily suspended and a new sequence of operations to begin, usually at a pre-determined address. The source of the signal may be internal or external.
INTER-SYMBOL INTERFERENCE	Interference between the waveform representing a symbol (one bit in binary-coded signalling) and other (usually adjacent) symbols in the data stream.
INTRA-FRAME CODING	Method of coding applicable to still pictures, or pictures which may be considered as still, within a sequence; the coding makes use of spatial correlations within the picture.
I/O	Input/Output. That group of logic which deals with the control of input data to, and output data from, a CPU.
ISO7-UK	The national version of the 7-bit character code set used for information processing interchange. An eighth 'parity' bit is frequently added. (Ref BS 4730:1974). See also ASCII.
K	1024 when referring to words of storage, i.e. $1K = 1024$ words, $4k = 4096$ words.
LANGUAGE	A set of representations, conventions and rules used to convey information.
LOADER	A program which produces a *machine code* program with *absolute addresses* from an object program input. The loader may also recognise symbolic references to external routines in which case it may scan an extensive object library to search for and to 'load' the required routines (in this case it is often called a *Linking Loader*).
MACHINE CODE	Code, usually binary, which can be used directly to set states of the hardware logic of the CPU as a means to implement an algorithm.
MACRO	Sequence of instructions (usually in assembly language) which are collectively given a symbolic name, possibly with parameters. Occurence of that name in the source program will result in expansion to the appropriate assembly language statements when the symbolic text is operated on by a macro-processor.
MAIN FRAME	The central processing unit of a computer plus the input/output unit and the random-access and read-only memories.

MICROPROGRAM — A computer program written usually in the most basic instructions, each often having direct control of the most-basic parts of the computer 'architecture'. Sequences of such instructions are often stored in high-speed read-only memory and are often only used by the systems designer to 'build' *machine code* instructions which are of more use to the user.

MULTIPROGRAMMING — A method by which many programs can be operated on within the same time span. The programs are overlapped or interleaved. This technique is the basis for time-shared operation.

NMOS — Metal Oxide Semiconductor logic devices utilising N-type silicon; are similar to PMOS devices. NMOS produces slightly faster gates than PMOS.

NRZ — Non-return-to-zero; a form of signalling in which the electrical wave rests only at one of two levels—never at an intermediate level.

NYQUIST FREQUENCY — Minimum sampling frequency which theoretically permits the original signal to be reconstructed without distortion.

OBJECT PROGRAM — The binary coded program which is generated by a compiler or assembler from the input source of symbols. The object program may be in direct *machine code* or may be in a relocatable binary-coded form. It may also contain symbols referring to subroutines which are not included in the main program (see LOADER).

OCTAL CODE — Code with base 8. It is convenient to use octal code for example when computer words are easily separable into three binary bits. $(2^3=8)$.

OFF-LINE — Pertaining to equipment or devices not under direct control of a computer.

ON-LINE — Pertaining to equipment or devices under direct control of a computer; also to programs operating directly and immediately to user commands.

PARITY — Parity checking is a method by which binary numbers can be checked for errors. In a sample parity check, an extra bit, called the parity bit, is added to make the sum of all the one's in the number consistently either odd or even depending on whether odd or even parity is specified.

PCM — Pulse-Code Modulation is a form of pulse modulation in which the pulse-height is modulated, (often in binary fashion; full height/zero height), to convey information, such as the successive sample values of a quantity.

PERIPHERAL — Any device outside the processor environment with which the processor can communicate via an interface.

PICTURE CODING — Coding of only the picture information in a video signal.

PMOS — Metal Oxide Semiconductor logic devices utilising P-type silicon, often referred to as simply MOS; it is a logic family in which the gates are made using Field Effect Transistors.

*PROGRAM LIBRARY — A collection of available computer programs and routines.

PROM — A Programmable ROM. A device which may be programmed by the *user*. Often used as a ROM for low volume production or development.

*Note: In a broadcasting environment the spelling 'program' is preferred to differentiate between computer *programs* and broadcast *programmes*.

PULSE MODULATION	Form of modulation in which information is conveyed by modulation of a property or properties of a pulse-train (pulse-position, pulse-height, pulse-width).
PUNCHED CARD OR TAPE	Paper tape or cards are punched with holes to represent a binary code. The punched data is prepared on- or off-line and is input to, or output from, the computer via photo-electric or electro-mechanical devices.
RAM	Random Access Memory. A device in which the logic states of individual storage elements can be recalled and modified during normal operation.
REGISTER	A device capable of storing a specified amount of data such as one word.
RELOCATABLE	A program is said to be relocatable if it can be loaded in any desired area of memory.
ROM	Read Only Memory. A device capable of storing permanently (or over considerable periods of time) data and instructions which cannot thereafter be modified in normal operation. ROMs therefore need to be programmed prior to incorporation in an equipment. (See also PROM).
ROUTINE	A program or part of a program.
RUN-LENGTH CODING	A method of coding in which information is transmitted on the number of successive samples having equal or nearly-equal values.
RZ	Return-to-Zero. A form of signalling in which the electrical wave rests at an intermediate state, between each excursion to either of two other states (denoting 1 and 0).
SLOPE OVERLOAD NOISE	The distortion arising from the inability of a coding system to follow rapid large-amplitude changes in the input signal.
SOFTWARE	The collection of programmes and routines for a computer.
SOURCE LANGUAGE OR SOURCE PROGRAM	A symbolic language or program that is input to a given translation process.
STACK	A dedicated buffer store used in conjunction with subroutine transfer and interrupt procedures and in which the last word or byte entered is the first to be recovered. The Stack is an example of a software controlled LIFO ('last in, first out') structure: entering a byte is known as 'pushing' and recovery as 'popping'.
SUB-NYQUIST SAMPLING	Sampling operation using a frequency below the Nyquist frequency.
TELETEXT	A system whereby a digital signal representing a number of pages of textual information and/or simple graphics is inserted into field blanking intervals of an otherwise normal television waveform which is then broadcast in the usual way. Thus, receivers incorporating suitable decoding circuits can, at the viewers option, display either the normal television programmes or the written information.
TERMINAL	An input or output device designed to receive or send source data.

TTY OR TELETYPEWRITER	A page printing device printing characters serially as in a typewriter, in response to 7- or 8- bit (ISO7/ASCII) codes. These codes are also generated by the associated keyboard for outward transmission, if required.
TRANSFORM CODING	Modification of either the analogue signal before digital coding or the digital signal after coding, in order to change its characteristics and achieve some desired special property in the coded signal.
VDU	Visual Display Unit. A means of presenting alpha numeric data and diagrams on a television display by dividing the available screen area into a matrix of rectangles within which characters or elemental graphics symbols can be displayed.
VIDEO CODING	Process of coding the complete composite video signal.
WORD	A computer word may consist of one or more bytes and the term is used to denote the unit of storage, particularly where this exceeds a single byte, (e.g. in a 16-bit machine, the byte is frequently regarded as 8-bits, so that each 16-bit word consists of two bytes).